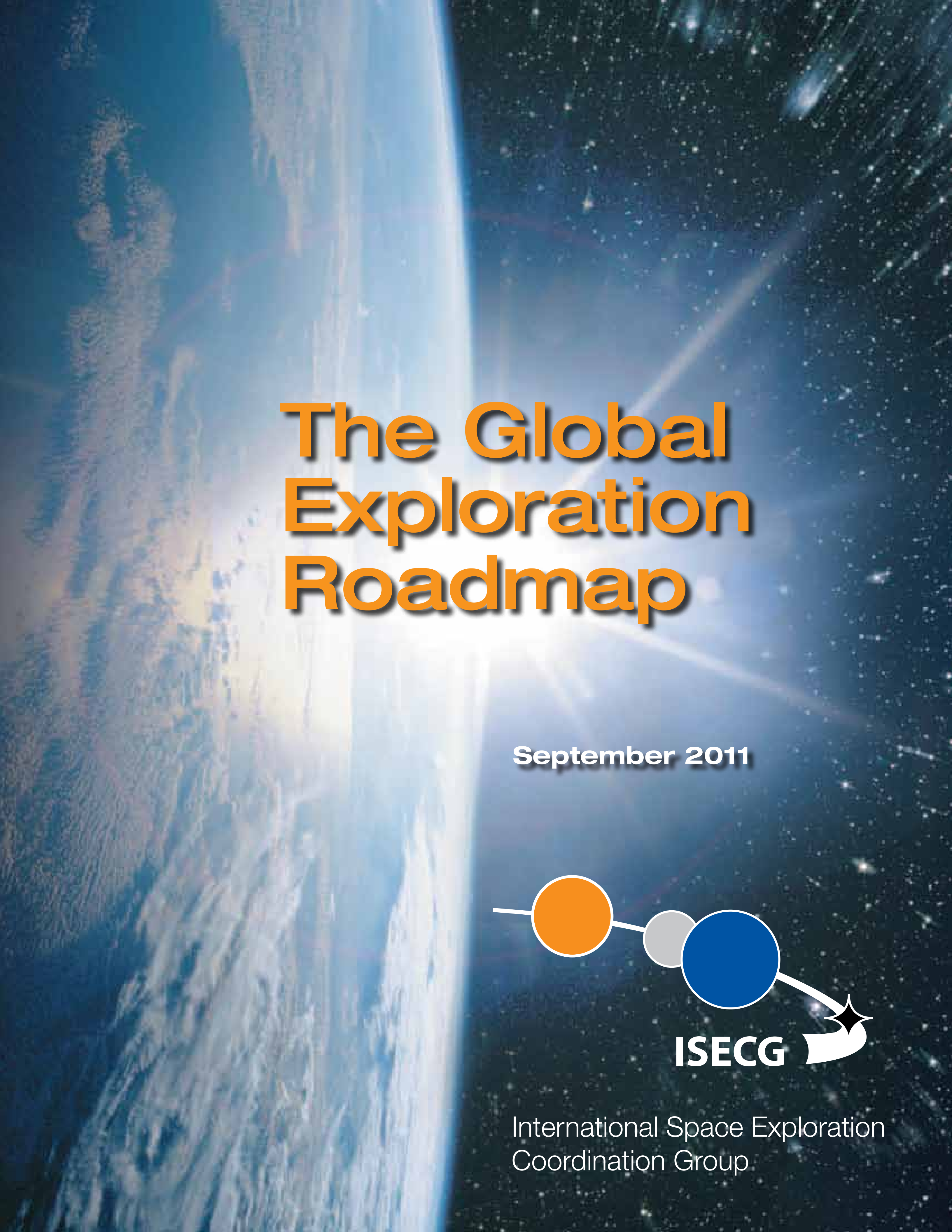
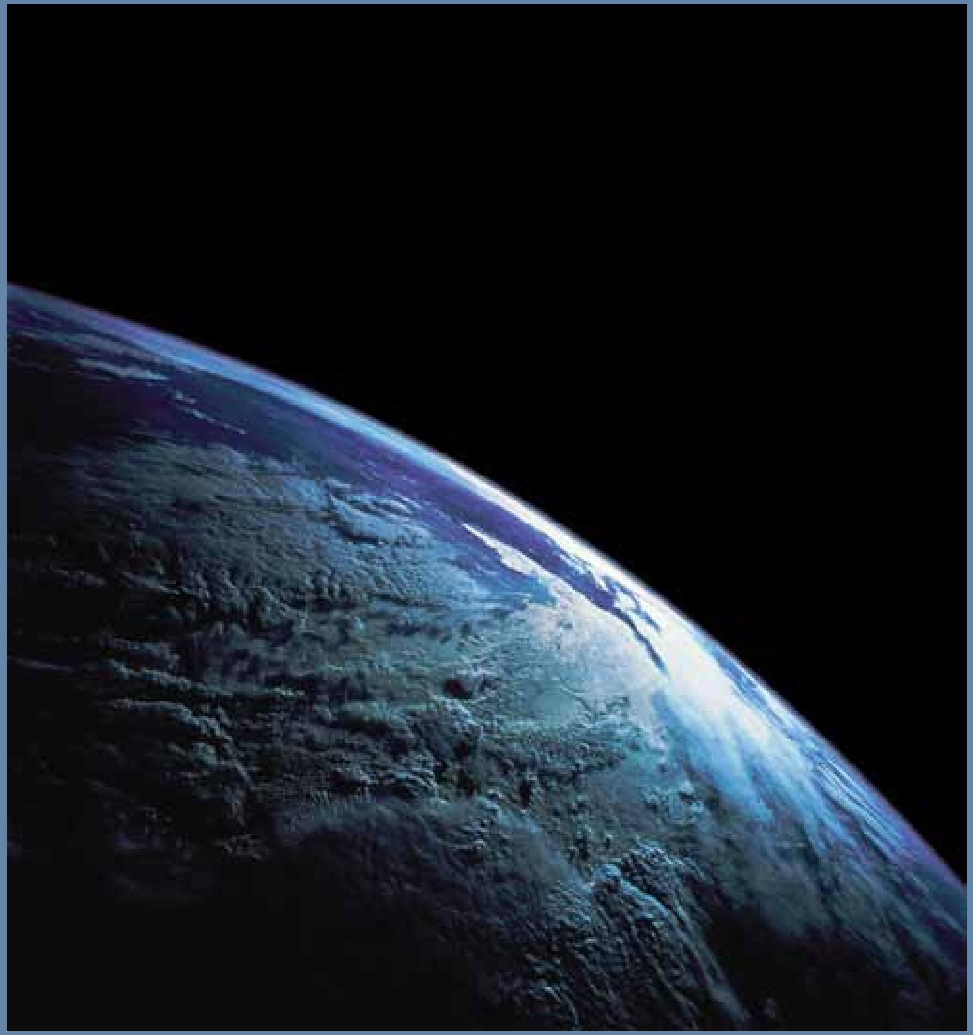


The Global Exploration Roadmap

September 2011

ISECG

International Space Exploration Coordination Group



"The surface of the Earth is the shore of the cosmic ocean.
From it we have learned most of what we know.
Recently, we have waded a little out to sea, enough to dampen
our toes or, at most, wet our ankles.
The water seems inviting. The ocean calls."

— Dr. Carl Sagan

The Global Exploration Roadmap

Human and robotic exploration of the Moon, asteroids, and Mars will strengthen and enrich humanity's future, bringing nations together in a common cause, revealing new knowledge, inspiring people, and stimulating technical and commercial innovation. As more nations undertake space exploration activities, they see the importance of partnering to achieve their objectives. Building on the historic flight of Yuri Gagarin on April 12, 1961, the first 50 years of human spaceflight have resulted in strong partnerships that have brought discoveries, innovations, and inspiration to all mankind. Discoveries we have made together have opened our eyes to the benefits of continuing to expand our reach.

International Space Exploration Coordination Group ISECG

What is the Global Exploration Roadmap?

Building on the vision for coordinated human and robotic exploration of our solar system established in *The Global Exploration Strategy: the Framework for Coordination*, released in May 2007, space agencies participating in the International Space Exploration Coordination Group (ISECG) are developing the Global Exploration Roadmap. The Global Exploration Roadmap reflects the international effort to define feasible and sustainable exploration pathways to the Moon, near-Earth asteroids, and Mars. Beginning with the International Space Station (ISS), this first iteration of the roadmap examines possible pathways in the next 25 years.

Agencies agree that human space exploration will be most successful as an international endeavor because there are many challenges to preparing for these missions and because of the significant social, intellectual, and economic benefits to people on Earth. This first version of the Global Exploration Roadmap represents a step in the international human space exploration roadmapping activity that allows agencies to be better informed as they prepare to play a part in the global effort. It will be updated over time to reflect evolving global consensus on exploration destinations and associated architectures.

By sharing early results of this work with the broader community, space agencies hope to generate innovative ideas and solutions for meeting the challenges ahead.

Italy

France

Canada

Germany

European Space Agency

India

Japan

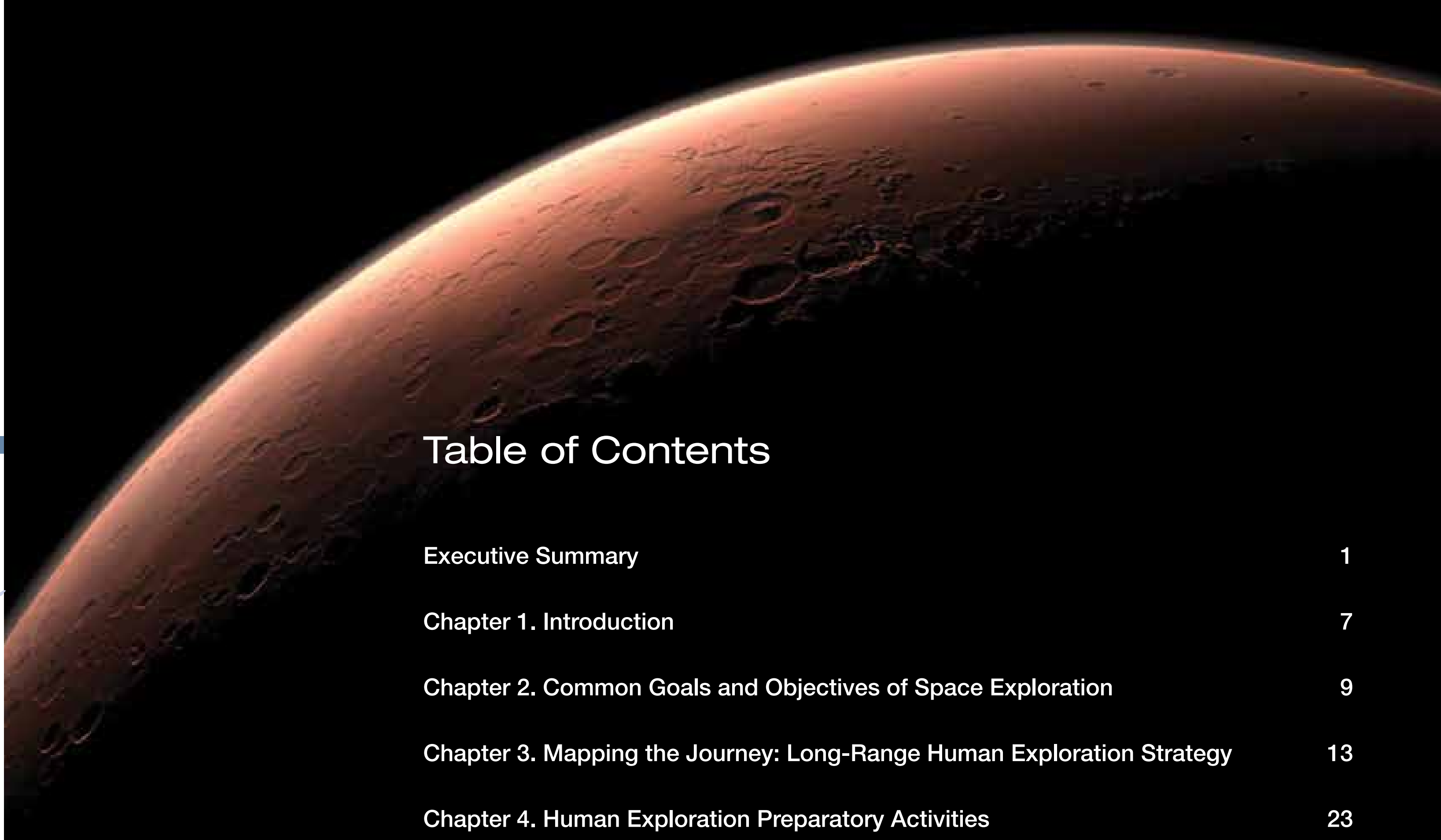
South Korea

United States

Ukraine

Russia

United Kingdom



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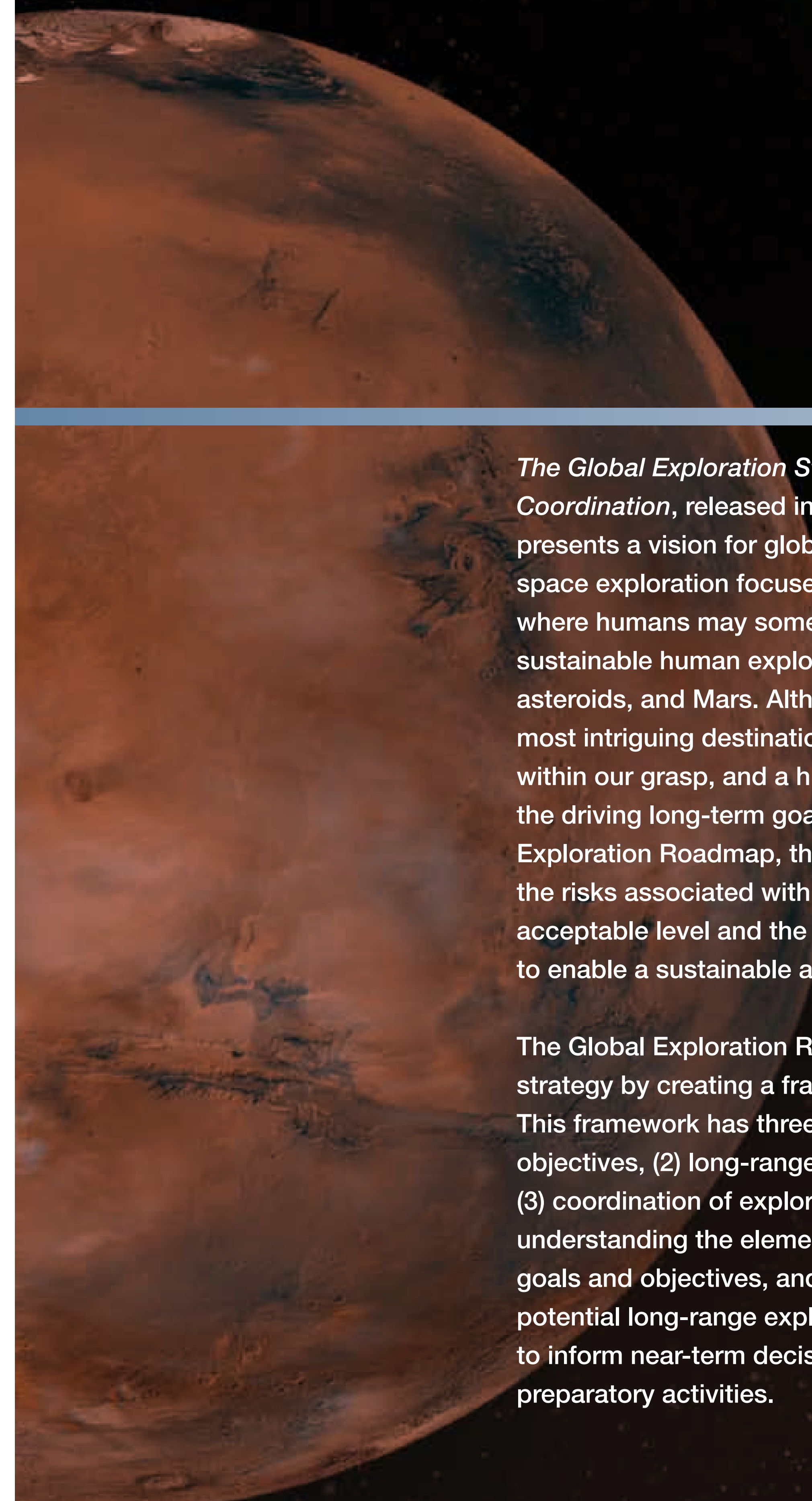
Daybreak over Gale Crater, Mars (Gale Crater was recently identified as the destination for the Mars Science Laboratory.)



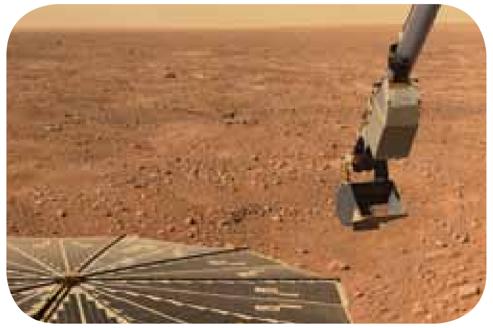
Executive Summary

The Global Exploration Strategy: the Framework for Coordination, released in May 2007 by 14 space agencies, presents a vision for globally coordinated human and robotic space exploration focused on solar system destinations where humans may someday live and work. It calls for sustainable human exploration of the Moon, near-Earth asteroids, and Mars. Although Mars is unquestionably the most intriguing destination for human missions currently within our grasp, and a human mission to Mars has been the driving long-term goal for the development of the Global Exploration Roadmap, there is much work to be done before the risks associated with such missions can be reduced to an acceptable level and the required technologies are matured to enable a sustainable approach.

The Global Exploration Roadmap further advances the strategy by creating a framework for interagency discussions. This framework has three elements: (1) common goals and objectives, (2) long-range human exploration scenarios, and (3) coordination of exploration preparatory activities. By understanding the elements common to their exploration goals and objectives, and by collaborating to examine potential long-range exploration scenarios, agencies seek to inform near-term decisions affecting their exploration preparatory activities.

Common Goals and Objectives

The Global Exploration Roadmap is driven by a set of goals and supporting objectives that reflect commonality while respecting each individual agency's goals and objectives. They demonstrate the rich potential for exploration of each of the target destinations, delivering benefits to all nations. The definitions of the goals and objectives listed below are the result of an iterative process and will reflect ongoing refinements as agency priorities evolve.



Search for Life
Determine if life is or was present outside of Earth and understand the environments that support or supported it.

Extend Human Presence
Explore a variety of destinations beyond low-Earth orbit with a focus on continually increasing the number of individuals that can be supported at these destinations, the duration of time that individuals can remain at these destinations, and the level of self-sufficiency.

Develop Exploration Technologies and Capabilities
Develop the knowledge, capabilities, and infrastructure required to live and work at destinations beyond low-Earth orbit through development and testing of advanced technologies, reliable systems, and efficient operations concepts in an off-Earth environment.

Perform Science to Support Human Exploration
Reduce the risks and increase the productivity of future missions in our solar system by characterizing the effect of the space environment on human health and exploration systems.

Stimulate Economic Expansion
Support or encourage provision of technology, systems, hardware, and services from commercial entities and create new markets based on space activities that will return economic, technological, and quality-of-life benefits to all humankind.

Perform Space, Earth, and Applied Science
Engage in science investigations of, and from, solar system destinations and conduct applied research in the unique environment at solar system destinations.

Engage the Public in Exploration
Provide opportunities for the public to engage interactively in space exploration.

Enhance Earth Safety
Enhance the safety of planet Earth by following collaborative pursuit of planetary defense and orbital debris management mechanisms.

Human Space Exploration Scenarios: Optional Pathways in a Common Strategy

The common human exploration strategy begins with the ISS as the first important step toward Mars and human expansion into space. It recognizes that human missions to both asteroids and the Moon are also important destinations that contribute to preparing for a future human mission to Mars.

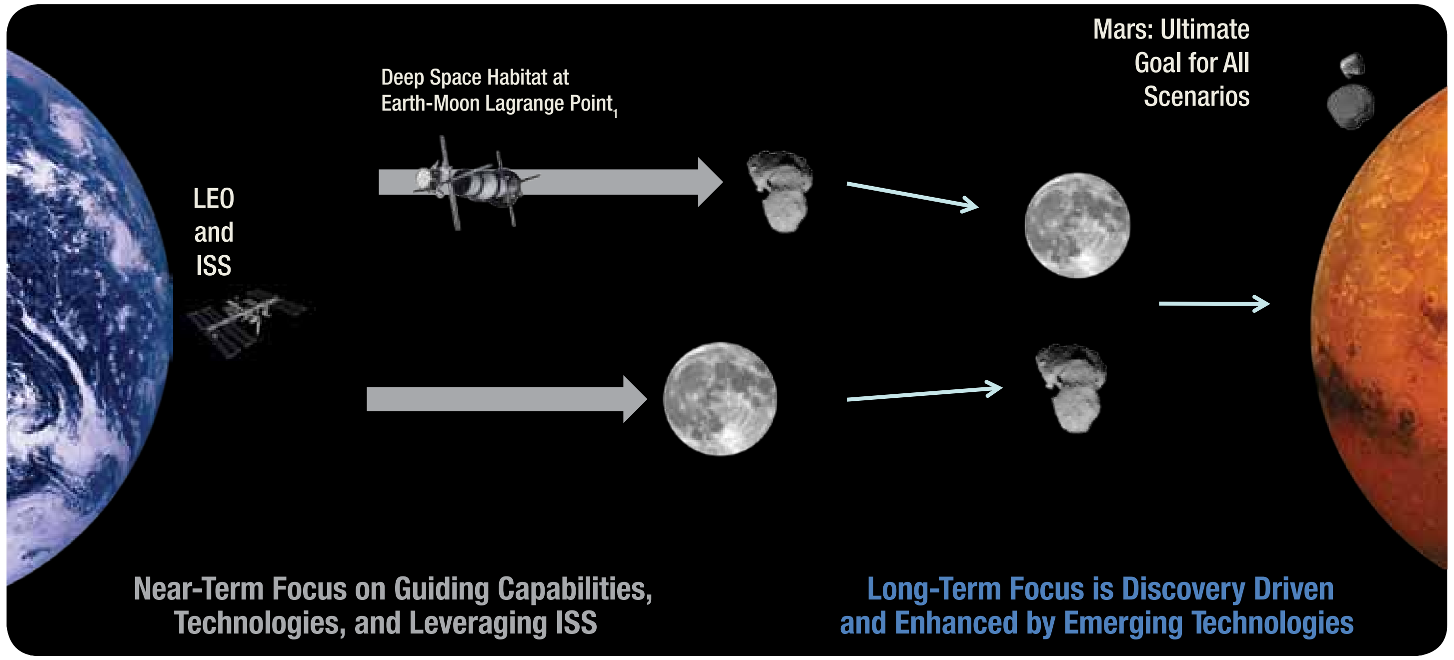
This first iteration of the roadmap identifies two feasible pathways for human missions after ISS: (1) Asteroid Next and (2) Moon Next. They differ primarily with regard to the sequence of sending humans to the Moon and asteroids, and each reflects a stepwise development and demonstration of the capabilities ultimately required for human exploration of Mars. Each pathway is elaborated by development of a representative mission scenario—a logical sequence of missions over a 25-year horizon—which is considered technically feasible and programmatically implementable.

For each mission scenario, a conceptual architecture was considered that included design reference missions and notional element capabilities. Design reference missions are generally destination focused, yet they comprise capabilities that are reused or evolved from capabilities used at other destinations.

To guide mission scenario development, agencies have reached consensus on principles that reflect common drivers. The six principles are listed below:

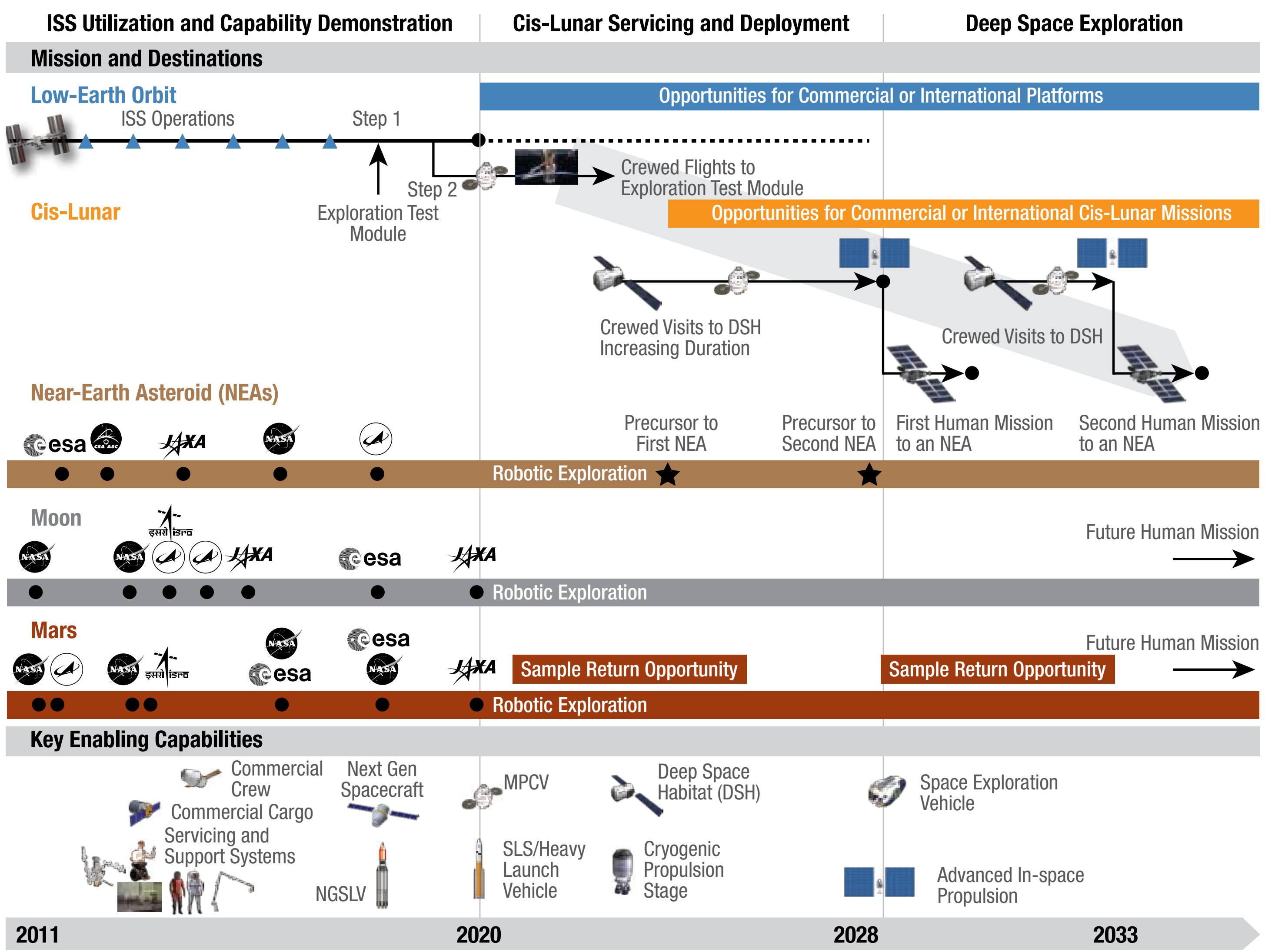
1. Capability Driven Framework: Follow a phased/stepwise approach to multiple destinations.
2. Exploration Value: Generate public benefits and meet exploration objectives.
3. International Partnerships: Provide early and sustained opportunities for diverse partnerships.
4. Robustness: Provide for resilience to technical and programmatic challenges.
5. Affordability: Take into account budget constraints.
6. Human-Robotic Partnership: Maximize synergy between human and robotic missions.

Optional Pathways in a Common Strategy

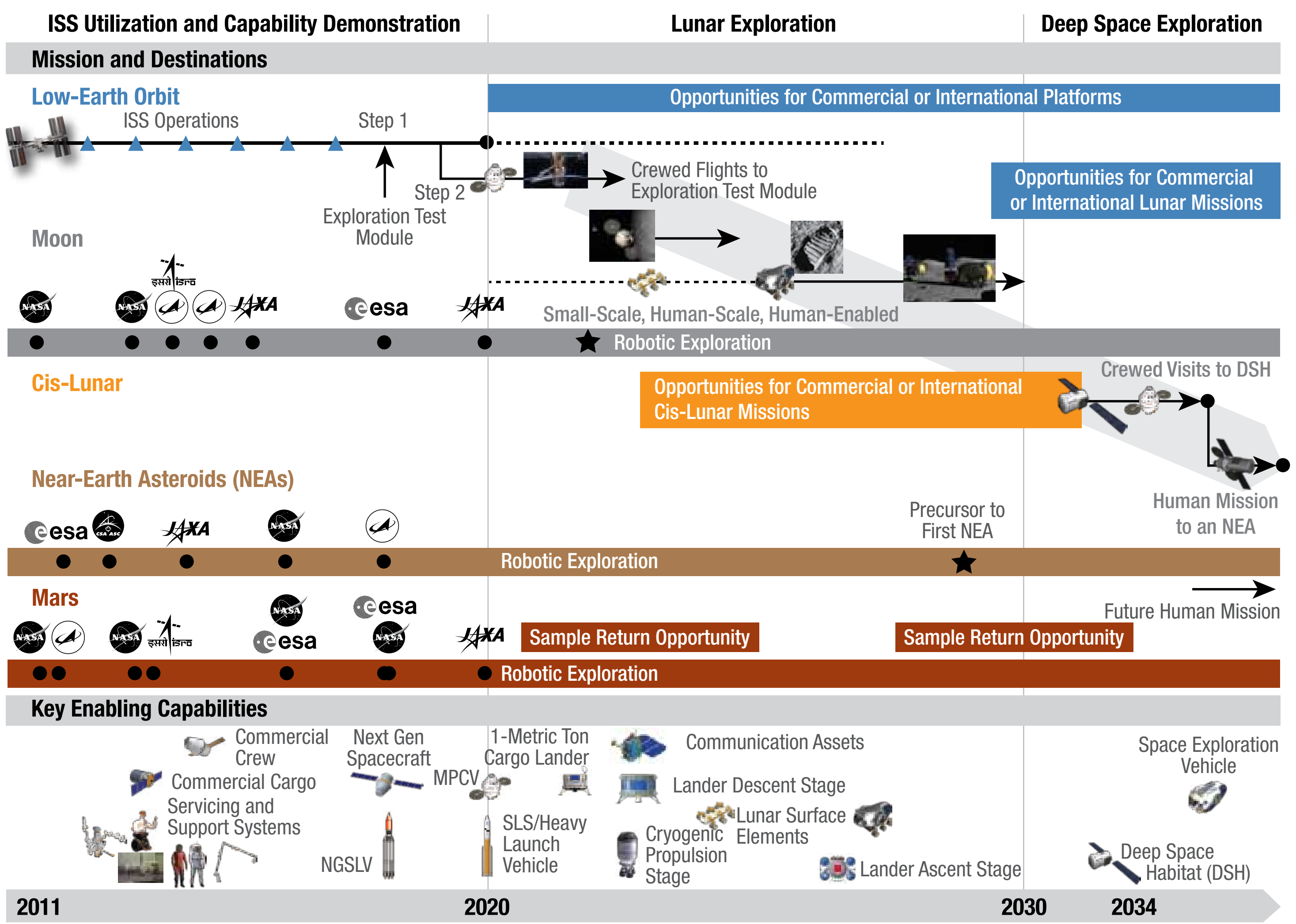


Two notional mission scenarios have been defined to guide the exploration planning activity. The mission scenarios enable collaborative work in defining the missions and capabilities needed to realize the goals and objectives guiding exploration of each destination.

Mission Scenario: Asteroid Next



Mission Scenario: Moon Next



Human Exploration Preparatory Activities

Across the globe, engineers and scientists are working on many of the essential preparatory activities necessary to extend human presence into space and explore the planet Mars. By developing a common roadmap, agencies hope to coordinate their preparatory investments in ways that maximize return on investments and enable earlier realization of their goals and objectives.

Significant activities are underway in the following areas, each presenting opportunities for coordination and cooperation.

Use of the ISS for Exploration

The recent decision by ISS partners to extend the life of the ISS until at least 2020 ensures that ISS can be effectively used to prepare for exploration, both by ISS partner agencies as well as through new partnerships with nations who are preparing exploration roles for themselves.

Robotic Missions

Robotic missions have always served as the precursors to human exploration missions. Precursor robotic missions are essential to ensure human health, safety, and the success of human missions and ensure maximum return on the investments required for subsequent human exploration.

Advanced Technology Development

No one agency can invest robustly in all the needed technology areas that represent key challenges for executing human missions beyond low-Earth orbit. Appropriately leveraging global investments in technology development and demonstration is expected to accelerate the availability of critical capabilities needed for human exploration missions.

Development of New Space Systems and Infrastructure

Human exploration beyond low-Earth orbit will require a new generation of capabilities and systems, incorporating technologies still to be discovered. They will be derived from and build on experience from existing competencies and lessons learned.

Analogue Activities

Testing in a relevant environment allows refinement of system designs and mission concepts, helping prepare for exploration beyond low-Earth orbit. Terrestrial analogue activities also provide an important opportunity for public engagement in a setting that brings together students, astronauts, scientists, and engineers.

Conclusion

This first iteration of the Global Exploration Roadmap shows that agencies have begun collaboratively working on long-range exploration mission scenarios. Two such notional scenarios have been elaborated and will further guide international discussion. The roadmap shows that agencies are looking for near-term opportunities to coordinate and cooperate that represent concrete steps toward enabling the future of human space exploration across the solar system.

The following key observations are made to assist in this effort:

1. Recognize that interdependency is essential and take steps to successfully implement it.
2. Realize additional opportunities for using the ISS.
3. Increase opportunities for enhancing the human-robotic science partnership.
4. Pursue opportunities for leveraging investments that advance critical exploration technologies.

The current global economic climate creates a challenge in planning for space exploration. Yet, it is important to start planning now. First, collaborative work on exploration mission scenarios will allow us to inform decisions made today regarding activities such as exploration technologies and use of the ISS. Second, the retirement of the U.S. Space Shuttle and the completion of the ISS assembly make available critical skills in a high-performing aerospace workforce. Focusing this global workforce will enable a smooth transition to the next destination beyond low-Earth orbit for human spaceflight.

Chapter 1. Introduction

The Global Exploration Strategy: the Framework for Coordination, released in May 2007 by 14 space agencies, presented a vision for globally coordinated human and robotic space exploration focused on solar system destinations where humans may someday live and work. In this vision, human exploration of the Moon, near-Earth asteroids, and Mars is preceded by robotic explorers that reveal many of their secrets, characterize their environments, and identify risks and potential resources. Human exploration follows in a manner that is sustainable and allows agencies to meet their goals and objectives.

From Research to Exploration to Utilization

Achieving the vision of sustainable human space exploration, including human missions to Mars, requires political support and resources over an extended period of time. It will also require the level of international commitment that has maintained the ISS partnership over the last 25 years. The success of the ISS Program, one of the most advanced international engineering achievements to date, demonstrates what is possible when space-faring nations collaborate and pursue a shared strategy.

The need to make human spaceflight more affordable will drive changes in the way we develop and operate exploration systems. Innovations in research and technology are essential. Solutions to the challenges of safe and sustainable human spaceflight also improve life on Earth, and as we tackle the challenges of sending humans further and faster into space, our investment will result in additional innovations benefiting life on Earth.

Exploration of space initiated more than 50 years ago has enabled successful commercial activities in Earth orbit mainly in communication, navigation, and Earth observation satellites. In recent years, companies have started to invest in providing commercial space exploration services in response to government demands or simply to offer a new service to the public.

Utilization of low-Earth orbit for human exploration—once the strategic domain of the few—will soon be available to many on Earth through a multitude of international commercial service providers. This is important because the extension of human presence beyond Earth orbit depends on successful commercial access for humans in low-Earth orbit.

The Global Exploration Roadmap strategy recognizes that sustainable exploration must actively enable creation of new markets and commerce, once governments have led the way. Just as we have established Earth orbit as an important economic sphere, so will we eventually strive to do the same at future exploration destinations.

Human exploration of the surface of Mars is our driving long-term goal and defines the most complex challenges that must be overcome. The pathway to Mars begins with the ISS, an important step toward human expansion into space. It includes exploring the Moon and some near-Earth asteroids, demonstrating innovative technologies, mastering capabilities, revealing new knowledge, stimulating economic growth and inspiring future engineers and scientists. Decisions regarding destination sequencing will not be made by ISECG but will follow national policy decisions and international consultation at multiple levels—informed by ISECG's work to collaboratively advance exploration architectures and mission designs.

Past studies of many agencies conclude that the Moon is the most suitable next step. Just 3 days from Earth, the Moon is seen as an ideal location to prepare people for learning how to live and work on other planetary surfaces. As a repository of 4-billion years of solar system history, it is also of interest to the science community. Alternatively, pursuing the "Asteroid Next" pathway aggressively drives advancements in deep space exploration technologies and capabilities such as advanced propulsion or habitation systems. As relics of the solar system formation, near-Earth asteroids are worthy of further study and take a major step toward readiness for Mars missions.

The current global economic climate creates a challenge in planning for space exploration. Yet, it is important to start planning now for several reasons. First, collaborative work on exploration mission scenarios will allow us to inform decisions made today regarding exploration technologies and ISS activities. Second, the retirement of the U.S. Space Shuttle and the completion of ISS assembly make available critical skills in a high-performing aerospace workforce.

By collaboratively working on technically feasible and programmatically implementable long-range scenarios and looking for near-term opportunities to coordinate and cooperate, we take concrete steps toward enabling the future of human space exploration across the solar system.

Chapter 2. Common Goals and Objectives of Space Exploration

Why shall we explore space? Development of a Global Exploration Roadmap should be based on a clear understanding of the outcomes expected by participating agencies. It is important that mission scenarios reflect what space agencies want to accomplish, as articulated by specific goals and supporting objectives of space exploration.

Duck Bay at Victoria Crater, Mars.

The Global Exploration Roadmap is driven by a set of common space exploration goals and supporting objectives defined collectively by participating space agencies. Some goals and objectives apply uniformly to all destinations in the Global Exploration Roadmap while others do not. For example, the "Search for Life" goal is central to the exploration of Mars but not a driver for the exploration of the Moon. The formulation of goals and objectives is an iterative process that must reflect ongoing refinement as agency priorities evolve.

The common goals are described below, and the supporting objectives are listed in the table that follows:

- **Search for Life.** Determine if life is or was present outside of Earth and understand the environments that support or supported it. The search for life is a central goal of space exploration. Pursuing this goal continues the cultural quest of humankind to determine whether we are alone in the universe and answers deeply rooted questions about our origin and evolution. The question of whether life exists beyond Earth has great philosophical and scientific significance.

- **Extend Human Presence**. Explore a variety of destinations beyond low-Earth orbit with a focus on continually increasing the number of individuals that can be supported at these destinations, the duration of time that individuals can remain at these destinations, and the level of self-sufficiency. Extending and sustaining human presence beyond low-Earth orbit is another central goal of space exploration. This enables humankind to live and work in space, to harness solar system resources for use in space and on Earth, and eventually to settle on other planets. Pursuing this goal expands the frontiers of humanity, opens doors to future utilization of space, and reshapes how we think of ourselves and our place in the universe.

- **Develop Exploration Technologies and Capabilities**. Develop the knowledge, capabilities, and infrastructure required to live and work at destinations beyond low-Earth orbit through development and testing of advanced technologies, reliable systems, and efficient operations concepts in an off-Earth environment. This goal establishes the fundamental capabilities to extend and sustain space exploration beyond low-Earth orbit. Pursuing this goal also yields spinoff products, new materials and manufacturing processes, and various technologies that can address major global challenges.

- **Perform Science to Support Human Exploration**. Reduce the risks and increase the productivity of future missions in our solar system by characterizing the effect of the space environment on human health and exploration systems. This is essential for human exploration and will enable a human presence across the solar system. Pursuing this goal also yields innovation for Earth-based health care.

- **Stimulate Economic Expansion**. Support or encourage provision of technology, systems, hardware, and services from commercial entities and create new markets based on space activities that will return economic, technological, and quality-of-life benefits to all humankind. Pursuing this goal generates new industries, spurs innovation in fields such as robotics and energy systems, and creates high-technology employment opportunities. As space activities evolve from government research to exploration to utilization, new economic possibilities may extend beyond low-Earth orbit to the Moon and elsewhere in the solar system.

- **Perform Space, Earth, and Applied Science**. Engage in science investigations of, and from, solar system destinations, and conduct applied research in the unique environment at solar system destinations. Pursuing this goal delivers valuable knowledge to society and deepens understanding of our home planet.

- **Engage the Public in Exploration**. Provide opportunities for the public to engage interactively in space exploration. Space agencies have a responsibility to return value directly to the public that supports them by disseminating knowledge and sharing in the excitement of discovery. A participatory approach to exploration helps provide this value and maximizes opportunities to leverage public contributions to exploration missions. Pursuing this goal also creates opportunities to educate and inspire citizens, particularly young people, and to contribute to the cultural development of communities.

- **Enhance Earth Safety**. Enhance the safety of planet Earth by following collaborative pursuit of planetary defense and orbital debris management mechanisms. Pursuing this goal lowers the risk of unforeseen future catastrophic asteroid collisions, as well as damage to current space assets in Earth orbit.

Key Supporting Objectives

Goal	Objective
Search for Life	Find evidence of past or present life.
	Explore the past or present potential of solar system destinations to sustain life.
Extend Human Presence	Explore new destinations.
	Increase opportunities for astronauts from all partner countries to engage in exploration.
	Increase the self-sufficiency of humans in space.
Develop Exploration Technologies and Capabilities	Test countermeasures and techniques to maintain crew health and performance, and radiation mitigation technologies and strategies.
	Demonstrate and test power generation and storage systems.
	Develop and test high-performance mobility, extravehicular activity, life support, and habitation capabilities.
	Demonstrate the use of robots to explore autonomously and to supplement astronauts' exploration activities.
	Develop and validate tools, technologies, and systems that extract, process, and utilize resources to enable exploration missions.
	Demonstrate launch and advanced in-space propulsion capabilities.
	Develop thermal management systems, including cryogenic fluid management capabilities.
	Learn how to best perform basic working tasks and develop protocols for operations.
	Test and demonstrate advanced entry-decent-landing technologies.
	Test automated rendezvous and docking, on-orbit assembly, and satellite servicing capabilities.
	Develop and demonstrate technologies to support scientific investigation.
	Develop space communications and navigation capabilities.

(continued)

Key Supporting Objectives *(continued)*

Goal	Objective
Perform Science to Support Human Exploration	Evaluate human health in the space environment.
	Monitor and predict radiation in the space environment.
	Characterize the geology, topography, and conditions at destinations.
	Characterize available resources at destinations.
	Evaluate the impacts of the surface, near-surface, and atmospheric environment on exploration systems.
Stimulate Economic Expansion	Provide opportunities for the integration of commercial transportation elements into the exploration architecture.
	Provide opportunities for the integration of commercial surface and orbital elements into the exploration architecture.
	Evaluate potential for commercial goods and services at destinations, including markets for discovered resources.
Perform Space, Earth, and Applied Science	Perform Earth observation, heliophysics, and astrophysics from space.
	Gather scientific knowledge of destinations.
	Gather scientific knowledge of solar system evolution.
	Perform applied research.
Engage the Public in Exploration	Use interactive hands-on communications tools to provide virtual experiences using real and live exploration data.
	Enlist amateur/citizen scientists to contribute to exploration-related knowledge collection.
Enhance Earth Safety	Characterize potential near-Earth asteroid collision threats.
	Test techniques to mitigate the risk of asteroid collisions with Earth.
	Manage orbital debris around the Earth.

Many agencies are still developing their objectives and will be for some time to come, so the initial set is expected to evolve as national objectives do, and as discussions on commonality proceed. It will be important to establish an exploration strategy that allows the sustainment and growth of each agency's aspirations for human spaceflight. An early dialog that builds an understanding of agency goals and objectives will contribute to the definition of a shared strategy and enable each agency to communicate their reasons for being part of the international effort.

As space agencies continue to refine their goals and objectives, they will share them, look for commonality, and ensure that the Global Exploration Roadmap reflects that commonality.

NASA astronauts Nicole Stott (left) and Cady Coleman (right) pose for a photo in the Cupola of the ISS.

NASA astronaut Ken Ham (left) and JAXA astronaut Soichi Noguchi (right) are pictured on the forward flight deck of Space Shuttle Atlantis while docked with the ISS.

Chapter 3. Mapping the Journey: Long-Range Human Exploration Strategy

Space agencies participating in ISECG have defined a long-range human exploration strategy that begins with the ISS and expands human presence throughout the solar system, leading to human missions to explore the surface of Mars. Unquestionably, sending humans to Mars in a manner that is sustainable over time will be the most challenging and rewarding objective of human space exploration in the foreseeable future. These missions will require new technologies and significant advances in the capabilities, systems, and infrastructure we have today.

Mars Mission Major Challenges:

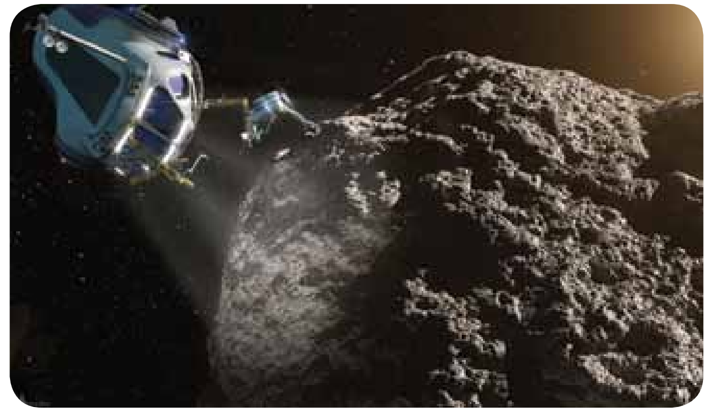
- Radiation protection and measurement techniques
- Subsystem reliability and in-space repair capability
- Entry, descent, and landing of large payloads
- Utilization of local resources, such as oxygen, water, and methane
- Advanced in-space propulsion
- Long-term storage and management of cryogenic fluids (H_2, O_2, CH_4, Xe)
- Surface mobility, including routine extravehicular activity capability

Transforming this strategy into a roadmap involves identification of feasible pathways and the definition of mission scenarios that build upon capabilities we have today, drive technology development, and enable scientific return.

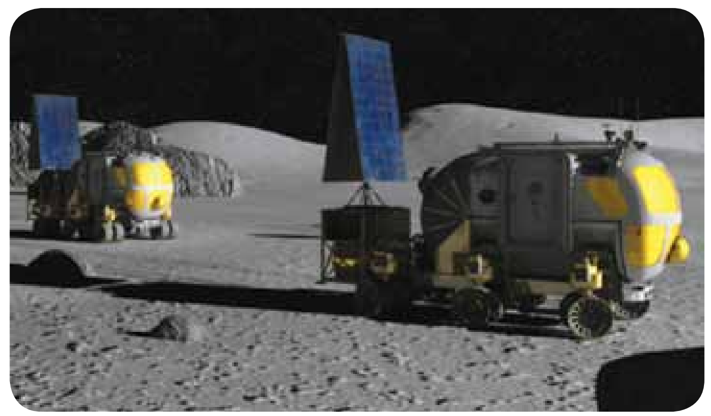
From Strategy to Roadmap: Exploration Pathways

As an important step toward human expansion into space, the ISS will allow agencies to perform research, technology demonstrations, and other activities on board this international laboratory. In addition, the ISS plays a key role in securing the economic viability of human exploration of low-Earth orbit by aggressively courting new research communities, addressing global challenges, simplifying operations concepts, and increasing the cost efficiency and quality of cargo and crew logistic services.

This first iteration of the roadmap identifies two feasible pathways for human missions after ISS: (1) Asteroid Next and (2) Moon Next. They differ primarily with regard to the sequence of sending humans to the Moon and asteroids, and each reflects a stepwise development and demonstration of the capabilities ultimately required for human exploration of Mars. Each pathway is elaborated by development of a representative mission scenario—a logical sequence of missions over a 25-year horizon—which is considered technically feasible and programmatically implementable.

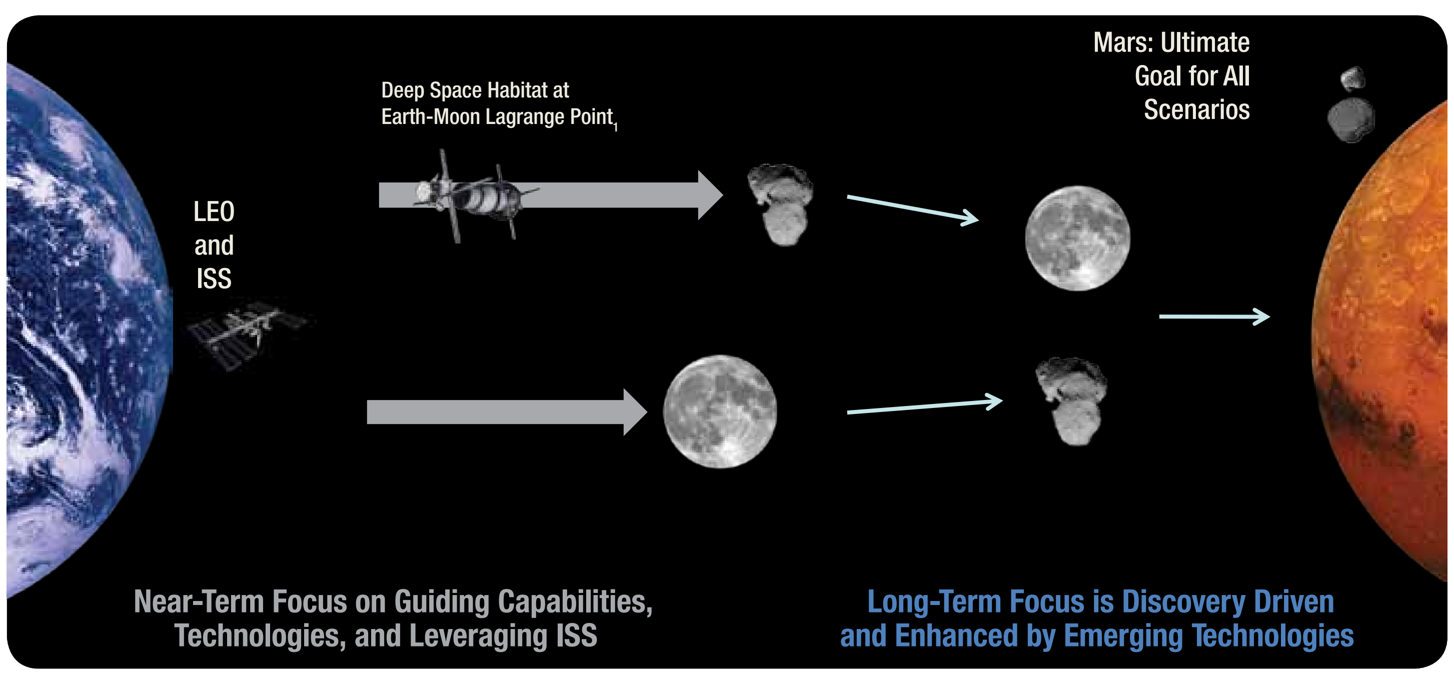


Humans interacting with a near-Earth asteroid, learning about the promise and risks of these primordial bodies.



Small pressurized rovers on the moon will increase crew mobility and can be reused at different landing sites.

Optional Pathways in a Common Strategy

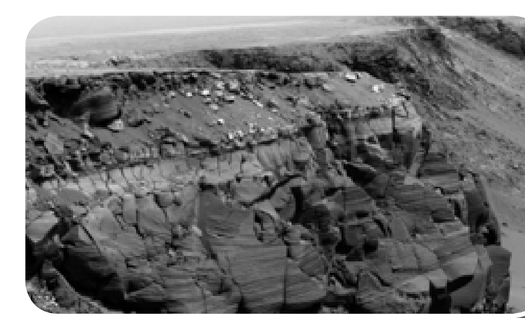


Feasible pathways consider exploration benefits and balance risk, cost, and overall technology readiness. Studies performed by individual agencies and within ISECG have identified key objectives and challenges that have influenced the definition of feasible pathways.

Summary of the Destination Assessment Activity

	Mars	Moon	Near-Earth Asteroid	LaGrange Points/Cis-Lunar Space
Key Objectives	Search for life. Advance understanding of planetary evolution. Learn to live on other planetary surfaces.	Characterize availability of water and other resources. Test technologies and capabilities for human space exploration. Advance understanding of solar system evolution. Utilize the Moon's unique importance to engage the public.	Demonstrate innovative deep space exploration technologies and capabilities. Advance understanding of these primitive bodies in solar system evolution and origin of life. Test methods to defend the Earth from risk of collisions with near-Earth asteroids.	Expand capability of humans to operate in this strategic region beyond low-Earth orbit. Demonstrate innovative deep space exploration technologies and capabilities.
Challenges	Significant technology advancements are essential for safe and affordable missions. Radiation risk and mitigation techniques must be better understood. Highly reliable space systems and infrastructure are needed. Demonstrated ability to use local resources is essential.	Expenses associated with extended surface activities.	Need to better understand and characterize the asteroid population. Technology advancements are needed before missions to asteroids.	Understanding the benefit of human presence vs. robots.

Other pathways, such as one that sets humans on the surface of Mars as the "next step," were evaluated based on work done within ISECG or by participating agencies. Typically, they were not considered feasible because of risk, cost, and technology readiness concerns or they did not sustain a cadence of missions considered essential to deliver value to stakeholders.



Cape St. Vincent Promontory, Mars.

Wopmay Rock, Mars.

Introduction to Mission Scenarios

For each mission scenario, a conceptual architecture was considered that included design reference missions and notional element capabilities. While design reference missions are generally destination focused, they will comprise capabilities that are reused or evolved from capabilities used at other destinations. In this way, an evolutionary approach to developing a robust set of capabilities to sustainably explore our solar system is defined. A graphical representation of design reference missions contained early in the scenarios and the key capabilities associated with them is on the following page.

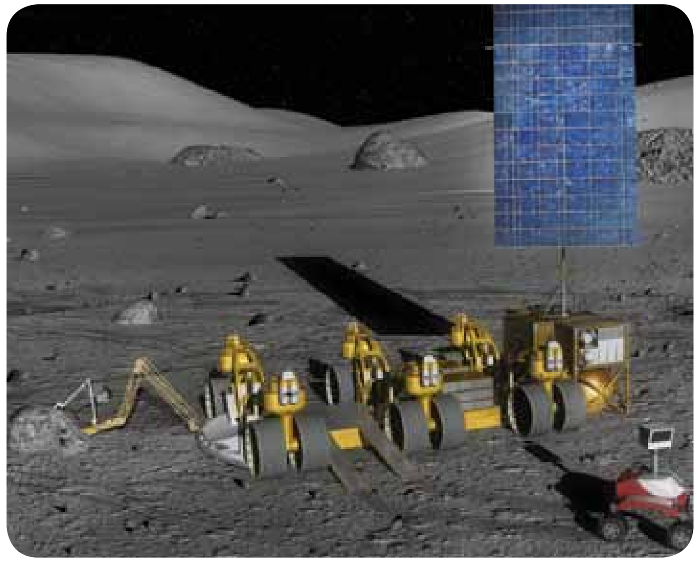
To guide mission scenario development, agencies have reached consensus on principles, such as affordability and value to stakeholders (see right). These principles have been informed by ISS lessons learned, but represent other considerations important to participating agencies. The selected mission scenarios are indicative of what can be done within the parameters of these agreed principles. Other mission scenarios within the identified pathways are possible. For this reason, the common principles should serve as a basis for exploring variations of the scenarios for meeting our goals and objectives.

Principles Driving the Mission Scenarios:

- Capability Driven Framework: Follow a phased/stepwise approach to multiple destinations.
- Exploration Value: Generate public benefits and meet exploration objectives.
- International Partnerships: Provide early and sustained opportunities for diverse partners.
- Robustness: Provide for resilience to technical and programmatic challenges.
- Affordability: Take into account budget constraints.
- Human-Robotic Partnership: Maximize synergy between human and robotic missions.

The work reflected in the Roadmap is conceptual and does not contain detailed cost, schedule, or risk analysis that would be necessary elements of program formulation. Specific mission plans and fully defined architectures will be developed by partner agencies as they advance specific exploration initiatives.

Near-Earth asteroids require true deep space missions, free of Earth's magnetosphere (deep space radiation environment), with only limited opportunities for abort.



The first human-scale robot on the Moon, demonstrating technologies to explore the surface of Mars.

Design Reference Missions and Capabilities

Common Capabilities		
	NASA Space Launch System (SLS)	Launch vehicle that has the capability to deliver cargo or crew from Earth to orbit.
	NASA Multi-purpose Crew Vehicle (MPCV)	Crew vehicle capable of delivering a crew to exploration destination and back to Earth.
	Roscosmos Next Generation Space Launch Vehicle (NGSLV)	Launch vehicle that has the capability to deliver cargo or crew from Earth to orbit.
	Roscosmos Next Generation Spacecraft	Crew vehicle capable of delivering a crew to exploration destination and back to Earth.
	Cryogenic Propulsion Stage (CPS)	In-space stage that provides delta V to architecture elements using traditional chemical rocket engines, cryogens, and storables and may include the capability for propellant transfer.
	Servicing Support Systems	Systems and tools to enable crew and robots to service in-space systems and assemble larger capabilities, including extravehicular activity suits.
	Commercial Crew	Commercial system capable of taking crew to low-Earth orbit.
	Commercial Cargo	Commercial system capable of taking cargo to low-Earth orbit.

"Asteroid Next" Design Reference Missions
Deep Space Habitat Deployment
Robotic Precursor Mission
Crew-to-Deep Space Habitat in E-M L1 — Short Stay
Crew-to-Deep Space Habitat in E-M L1 — Long Stay
Crewed Near-Earth Asteroid Mission using Advanced Propulsion

Unique Capabilities		
	Deep Space Habitat	An in-space habitat with relevant subsystems for the purpose of advancing capabilities and systems requiring access to a deep space environment.
	Advanced In-Space Propulsion Stage	In-space stage using nontraditional propulsion technologies, such as high-power electric and nuclear propulsion.
	In-Space Destinations Systems	These systems have the capabilities that enable humans to effectively complete in-space destination objectives by enabling access.

"Moon Next" Design Reference Missions
Robotic Precursor Mission
Crew-to-Low Lunar Orbit
Crew-to-Lunar Surface — 7-day Sortie Mission
Crew-to-Lunar Surface — 28-day Extended Stay Mission
Cargo-to-Lunar Surface (small)
Cargo-to-Lunar Surface (large)

Unique Capabilities		
	Lunar Cargo Descent Stage	System designed to land payload of up to 8-metric tons on the lunar surface.
	Lunar Ascent Stage	Works in combination with the largest descent stage as a system for transporting crew to and from the surface of the Moon.
	Surface Elements	These systems have the capabilities that enable humans to effectively complete surface destination objectives.
	1-Metric Ton Cargo Lander	System designed to land up to 1-metric ton on the lunar surface.

To Mars With Deep Space Asteroid Missions as the Next Step

This scenario pursues human exploration of near-Earth asteroids as the next destination. It offers the opportunity to demonstrate many of the capabilities necessary to send astronauts to Mars orbit and return them safely to the Earth. The mission scenario includes deployment of the deep space habitat in cis-lunar space to demonstrate the capabilities necessary for traveling and living in deep space. When hardware reliability and operational readiness are demonstrated, the deep space habitat will accompany other capabilities for the journey to an asteroid.

Missions to asteroids will then allow us to learn more about these primordial objects and examine techniques and approaches that may one day serve for planetary defense purposes.

The success of this scenario depends on the availability of suitable near-Earth asteroid human mission targets. Suitability includes such factors as achievable mission trajectories, acceptable physical characteristics for crewed operations, and scientific interest. Since only a small percentage of the total near-Earth asteroid population has been discovered and cataloged, identifying targets that provide flexibility in selection of crewed mission opportunities to achieve most objectives will be essential to the viability of this strategy as a pathway to eventual human missions to Mars.

This scenario develops the capabilities necessary to demonstrate crewed missions in space for longer durations at increased distances from Earth. Also demonstrated are critical capabilities, such as radiation protection and reliable life support systems, to support the longer duration trip times required to send astronauts to Mars orbit and return them safely to Earth. Successful human exploration of near-Earth asteroids will necessitate mastery of advanced propulsion technologies, which are essential for the safe and affordable exploration of Mars.

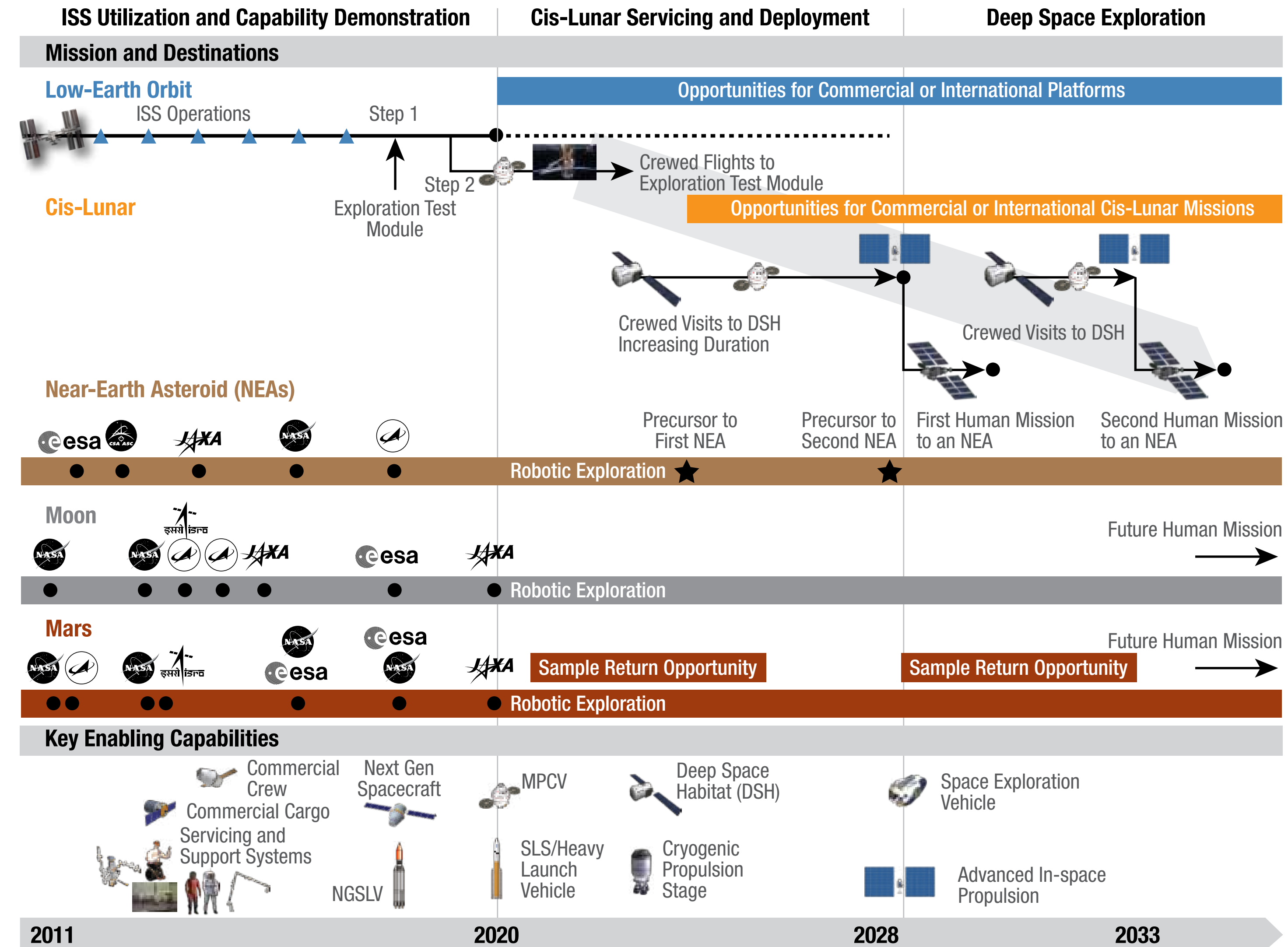
Some agencies are studying human missions to the Martian moons, Phobos and Deimos. While the benefits provided by human missions must be understood, these missions may also provide the opportunity to demonstrate similar capabilities as those required for asteroid missions.

Key features of this mission scenario include the following:

- Targeted utilization of the ISS to advance exploration capabilities
- Continued availability of low-Earth orbit access through commercial/international service providers
- Opportunities to demonstrate human operations in cis-lunar space, enabling future missions such as satellite servicing/deployment
- The early deployment of the deep space habitat to Earth-Moon Lagrange point 1 (EML 1), allowing demonstration of habitation and other critical systems in a deep space environment
- Progressively longer demonstrations of the ability to live without a regular supply chain from Earth
- "Technology Pull" for technologies such as advanced propulsion and large scale in-space power generation required for human Mars missions
- Two asteroid missions, each with a crew of four. These are preceded by robotic precursor missions that may visit multiple potential asteroid targets to characterize the risk and scientific priorities for each potential target

The Japan Aerospace Exploration Agency's (JAXA's) Hayabusa 2 will gather data informing future proximity operations and station keeping, as well as information on the composition of the C-type asteroid, 1999 JU3.

Mission Scenario: Asteroid Next



Evolutionary Strategy Demonstrating Technologies Needed for Mars Mission—Asteroid Next		
ISS/LEO	**Cis-lunar**	**Near-Earth Asteroids**
• Advancing in-space habitation capability for long durations • Subsystem high reliability and commonality, repair at the lowest level • Advanced extravehicular activity and robotics capabilities • Long-term storage and management of cryogenic fluids • Simulation of Mars mission operational concepts	• In-space habitation for long durations in the appropriate radiation environment • Radiation protection and measurement techniques • Demonstration of beyond low-Earth orbit re-entry speeds • Automated delivery and deployment of systems • Subsystem high reliability and commonality, repair at the lowest level—living without a supply chain • Long-term storage and management of cryogenic fluids • Simulations of near-Earth asteroid mission operational concepts	• Demonstration of in-space habitation capability for long durations • Demonstration of advanced in-space propulsion systems • Long-term storage and management of cryogenic fluids • Automated delivery and deployment of systems • Subsystem high reliability and commonality, repair at the lowest level—living without a supply chain • Demonstration of Mars mission transportation operational concepts

To Mars With the Moon as the Next Step

This scenario pursues human exploration of the Moon as the next destination. The Moon is seen as an ideal location to prepare people for learning how to live and work on other planetary surfaces. It also holds a wealth of information about the formation of the solar system, and its proximity and potential resources make it an important destination in expanding human presence.

This scenario develops the capabilities necessary to explore and begin to understand how to live self-sufficiently on a planetary surface. Also demonstrated are certain capabilities to support Mars mission landings, such as precision landing and hazard avoidance. Initial flights of the cargo lander not only demonstrate its reliability but deliver human-scale robotic systems that will conduct science and prepare for the human missions to follow. The period between the initial delivery of human-scale robotics and human missions will allow target technologies to be demonstrated and human/robotic operational techniques to be developed. When humans arrive, they will perform scientific investigations of the polar region, travelling enough terrain to master the technologies and techniques needed for Martian exploration. They will also aid the robotic assessment of availability and extractability of lunar volatiles.

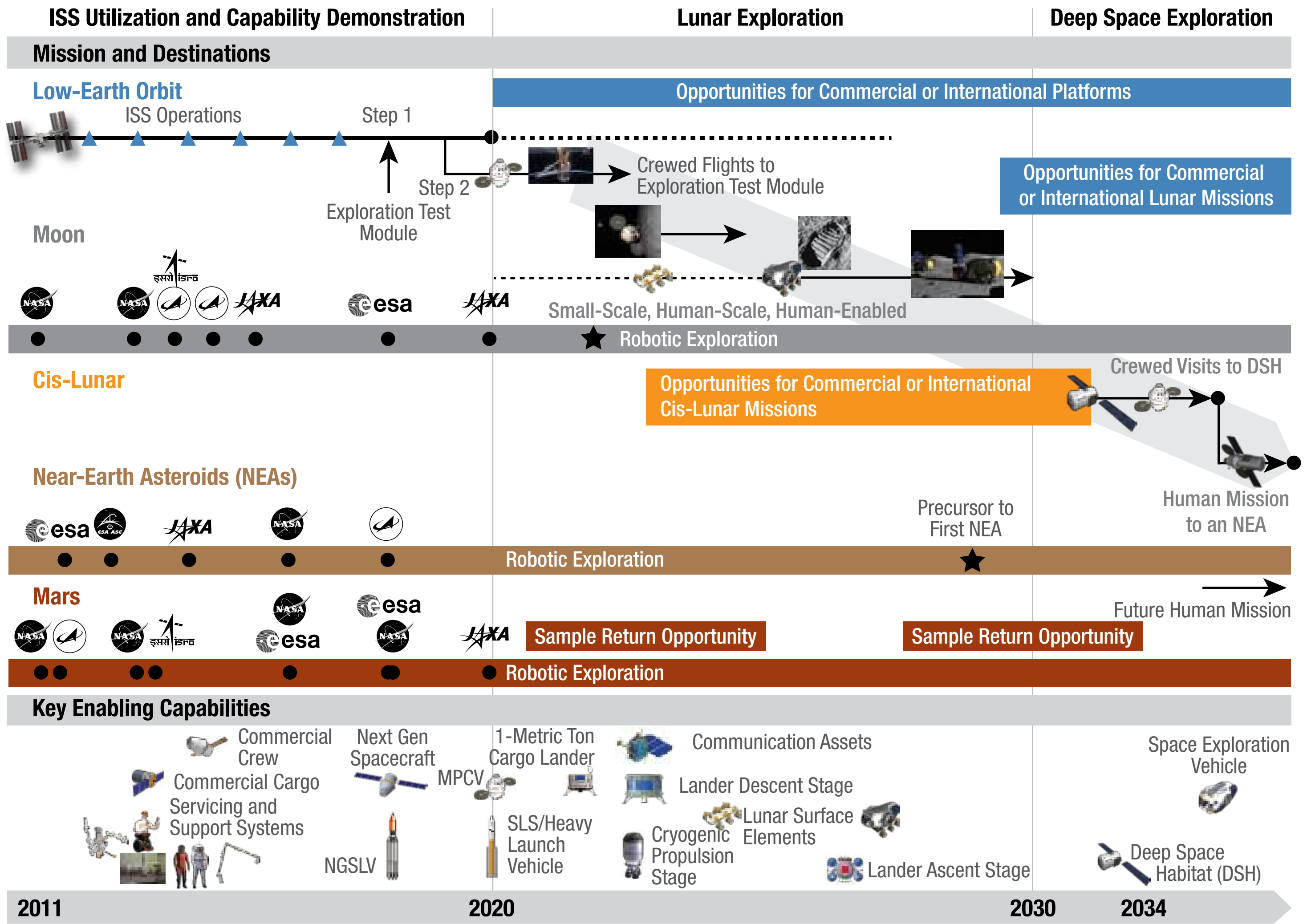
After the lunar missions, exploration of near-Earth asteroids would follow. These missions require additional capabilities, yet are an important step in preparation of future missions to the Mars. In-space systems with increased ability to support longer missions at increased distances from Earth would be necessary to reaching Mars orbit and surface.

Key features of this mission scenario include the following:

- Targeted utilization of the ISS to advance exploration capabilities
- Continued availability of low-Earth orbit access through commercial/international service providers
- A human exploration approach that builds on the large number of lunar robotic missions planned during 2010–2020 to inform detailed scientific and in situ research utilization objectives
- Early deployment of medium cargo lander and large cargo lander, sized to ultimately serve as part of a human landing system, along with the deployment of a human-scale rover chassis to advance robotic exploration capability
- Five extended-stay missions for a crew of four, exploration of polar region with long-distance surface mobility while demonstrating capabilities needed for Mars exploration
- "Technology Pull" for technologies such as long distance surface mobility, dust management and mitigation techniques, planetary surface habitation, precision landing, and, if desired, advanced surface power
- A limited, yet adaptable, human lunar campaign that may be extended to perform additional exploration tasks, if desired, or perhaps enable economically driven utilization in the long term, if warranted.

Chandrayaan-1 mapped the chemical characteristics and three dimensional topography of the Moon and discovered water molecules in the polar regions of the Moon.

Mission Scenario: Moon Next



Evolutionary Strategy Demonstrating Technologies Needed for Mars Mission — Moon Next		
ISS/LEO	**Moon**	**Near-Earth Asteroids**
• In-space habitation for long durations • Subsystem high reliability and commonality, repair at the lowest level • Advanced extravehicular activity and robotics capabilities • Long-term storage and management of cryogenic fluids • Simulation of operational concepts	• Surface habitation capabilities • Mars surface exploration scenarios, operations and techniques: long-range mobility, automated predeployment • Capabilities and techniques for extended operation in a dusty environment • Demonstration of beyond low-Earth orbit re-entry speeds • Advanced surface power if available • Extreme surface mobility • Robust, routine extravehicular activity capability • Precision landing and hazard avoidance	• Demonstration of in-space habitation capability for long durations • Demonstration of advanced in-space propulsion systems • Long-term storage and management of cryogenic fluids • Automated delivery and deployment of systems • Subsystem high reliability and commonality, repair at the lowest level — living without a supply chain • Demonstration of Mars mission transportation operational concepts

The ISS backdropped by the blackness of space and Earth's horizon.

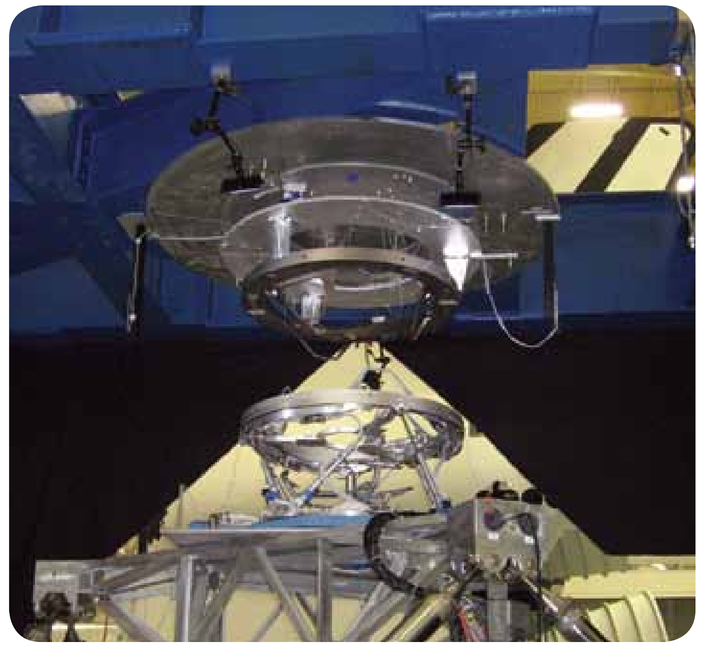
Further Steps in Defining Mission Scenarios Today

Subsequent iterations of the Global Exploration Roadmap will incorporate updates to these mission scenarios, reflecting updated agency policies and plans as well as consensus on innovative ideas and solutions proposed by the broader aerospace community. Ultimately, the roadmap will reflect the possible paths to the surface of Mars.

There are other near-term activities expected to influence the evolution of the mission scenarios. For example, lessons learned from the ISS Program[1], have guided early exploration planning activities. Recommendations such as the importance of considering dissimilar redundancy and defining standards and common interfaces to promote interoperability paves the way for future architecture and systems development. For example, the ISS partnership released the International Docking System Standard, which will allow future crew and cargo vehicles to dock or berth and service the ISS or any other space infrastructure that carries the standard interface.

Space agencies have already initiated discussions on common interfaces and standards such as the International Docking System Standard by the ISS partners. It is vitally important that efforts like this continue.

In addition, partnering between agencies where each provides capabilities on the critical path to completion of mission objectives has become common as mission complexity increases and interagency relationships become



A prototype of the NASA docking system that meets International Docking System Standards requirements undergoes dynamic testing at the NASA Johnson Space Center.

stronger. This is true for both human and robotic exploration initiatives. Large multinational exploration missions will require agencies to accept and manage interdependency at different levels: architecture, mission, infrastructure, and systems. The level of interdependency required of human exploration will necessitate advances beyond our current experience and increase interoperability across the architecture.

Observation

➔ Space agencies should take steps to define and manage the factors affecting interdependency at the architecture, mission, infrastructure and systems level, in order to enable a successful exploration initiative.

[1] ISS Lessons Learned as applied to Exploration, July 22, 2009

Chapter 4. Human Exploration Preparatory Activities

Across the globe, engineers and scientists are working on many of the essential preparatory activities necessary to extend human presence into space and explore the planet Mars. By developing a common roadmap, agencies hope to coordinate their preparatory activities in ways that maximize return on investments and enable realization of their goals and objectives.

Significant activities are underway in the following areas, each presenting opportunities for near-term coordination and cooperation.

- Use of the ISS for exploration
- Robotic missions
- Advanced technology development
- Development of new space systems and infrastructure
- Analogue activities

STS-133 Flyaround of ISS.

Cosmonaut Gennady Padalka performs a musculoskeletal ultrasound examination on crewmember Mike Fincke. Ultrasound use on the ISS has pioneered procedures for immediate diagnosis of injuries and other medical conditions, providing money-saving advancements in the practice of clinical and telemedicine.

Use of ISS for Exploration

The ISS plays a key role in advancing the capabilities, technologies, and research needed for exploration beyond low-Earth orbit. Since the first element was deployed, 13 years ago, the ISS has advanced the state of the art through numerous demonstrations and investigations in critical areas. As shown at the right, research and technology development in critical areas such as habitation systems and human health research will enable reducing risks of long-duration missions. Demonstration of exploration technologies, including advance robotics and communication technologies will inform exploration systems and infrastructure definition.

There are additional opportunities for using the ISS to prepare for exploration. The recent decision by ISS partners to extend the life of the ISS until at least 2020 ensures these opportunities can be realized. While the additional activities are not firmly funded within ISS partner agencies yet, they represent exploration priority areas. In coordination with the ISECG, the ISS Multilateral Coordination Board has formed a team to study possible technology collaboration initiatives based on the ISECG mission scenarios. These technology demonstrations on the station will support implementation of missions to asteroids, the Moon, and Mars. It should also be noted that the ISS partnership is interested in making access to the ISS available to non-ISS partner nations who are preparing exploration roles for themselves.

Many technologies initially demonstrated on ISS may benefit from integration into automated or free-flying platforms in the ISS vicinity. For example, advanced electric propulsion systems, inflatable habitation modules, and advanced life support systems can benefit from free-flyers that allow demonstration of standalone capabilities, exploration interfaces, or environmental conditions.

Essential Technology and Operations Demonstrations on ISS

Highly Reliable Habitation and Life Support Systems

Deep space exploration necessitates reducing our dependence on the supply chain of spares and consumables from Earth. Critical functions such as water recovery and management, air revitalization, and waste management must operate reliably and in a closed-loop manner.

Human Health and Performance

Understanding the risks to human health and performance, such as the effects of radiation and developing the capabilities to mitigate the risks is essential for keeping crews healthy and productive. In addition, advances in clinical real-time diagnostic capabilities will be needed to address health issues that arise during long missions.

Demonstration of Exploration Capabilities

ISS provides a unique space and operational environment to demonstrate reliability and key performance parameters of capabilities such as inflatable habitats, next generation universal docking systems, and robotic systems.

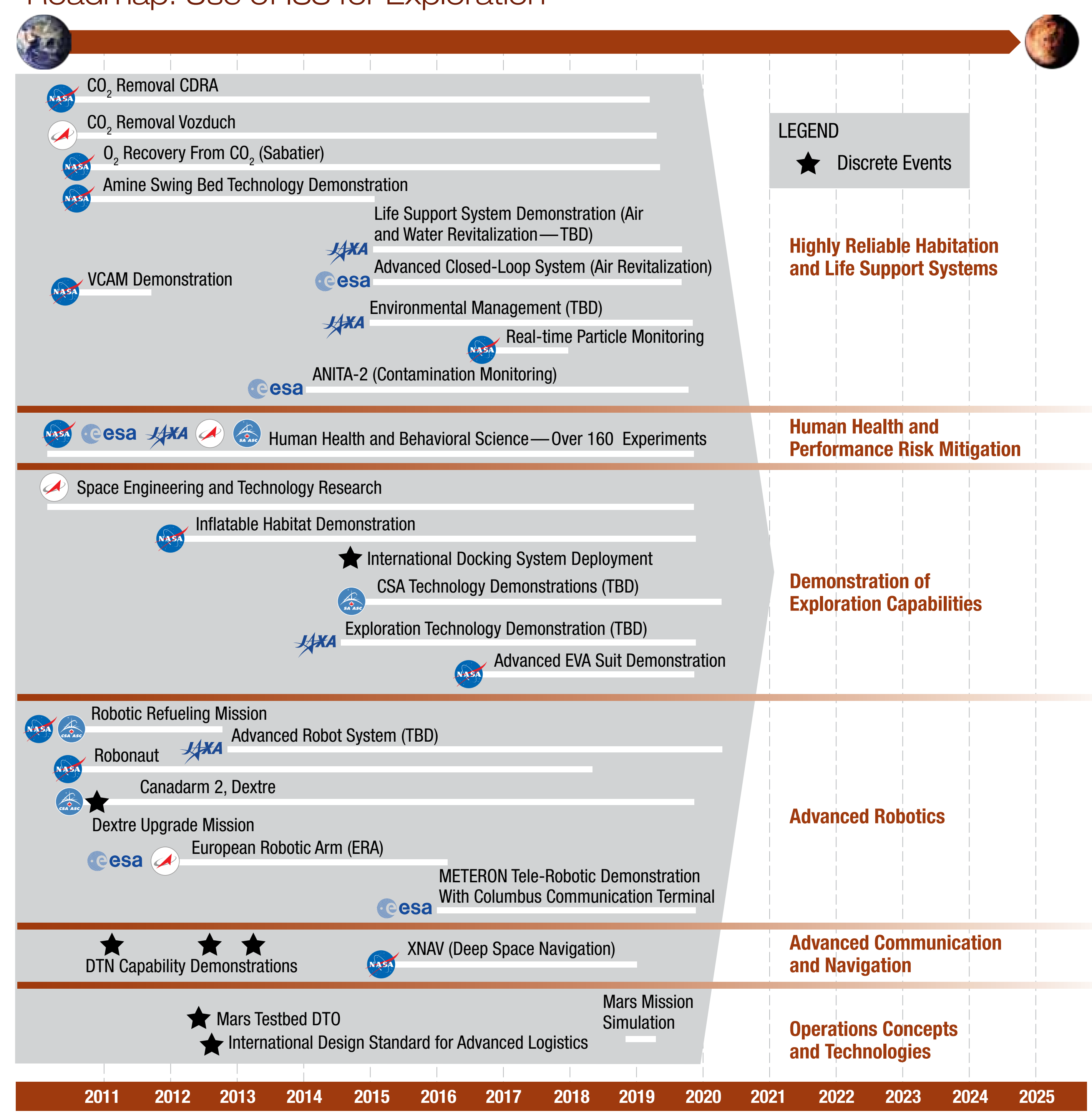
Advanced Communication and Space Internetworking Capabilities

The ISS will be configured to serve as a testbed for advanced communications and networking technologies, such as extension of the Internet throughout the solar system. Key to this will be to determine how to deal with the long time delays and communications disruptions inherent in deep space communication. Several disruptive tolerant networking nodes will be established within the ISS.

Operations Concepts and Techniques

The ISS provides the opportunity to simulate autonomous crew operations and other modes of operation consistent with Mars mission challenges. It also provides the high-fidelity environment to test alternative concepts of systems failure management, advanced diagnostic and repair techniques.

Roadmap: Use of ISS for Exploration



This roadmap indicates work ongoing or planned in the areas where essential advancements are needed, and the ISS provides the best opportunity to demonstrate them.

Observation

➔ ISS plays an essential role in preparing for exploration. ISS partner agencies should establish and implement plans that create additional opportunities to advance capabilities, demonstrate technologies, and test operational protocols and techniques in a timeframe that ensures their readiness for beyond low-Earth orbit missions.

Mars Exploration Rover begins exploring Mars.

Robotic Missions: An Invaluable Contribution to Human Exploration

Robotic missions have always served as the precursors to human exploration missions. Starting with Project Apollo, precursor robotic missions such as Rover, Surveyor, and Lunar Orbiter defined the boundary conditions and environments necessary to inform future human exploration of the Moon. These robotics missions identified potential hazards and characterized areas of the lunar surface for subsequent human exploration and scientific investigation. Similarly, several robotic missions have been sent to Mars in the recent years and these have consisted of remote sensing orbital spacecraft, landers, and exploration rovers. Much like the robotic missions to the Moon, these missions have obtained critical data on the Martian surface and atmospheric environment that will guide the development and operational concepts of exploration systems.

Robotic missions planned in the decade from 2010 to 2020 will make important contributions to the body of knowledge of the Moon, asteroids, Mars and its moons and enable maximum return on the investments required for subsequent human mission. In addition, continued robotic exploration in conjunction with future human activities complements both the expansion of humanity beyond low-Earth orbit and the scientific understanding of the Universe.

DLR Mars Crawler concept.

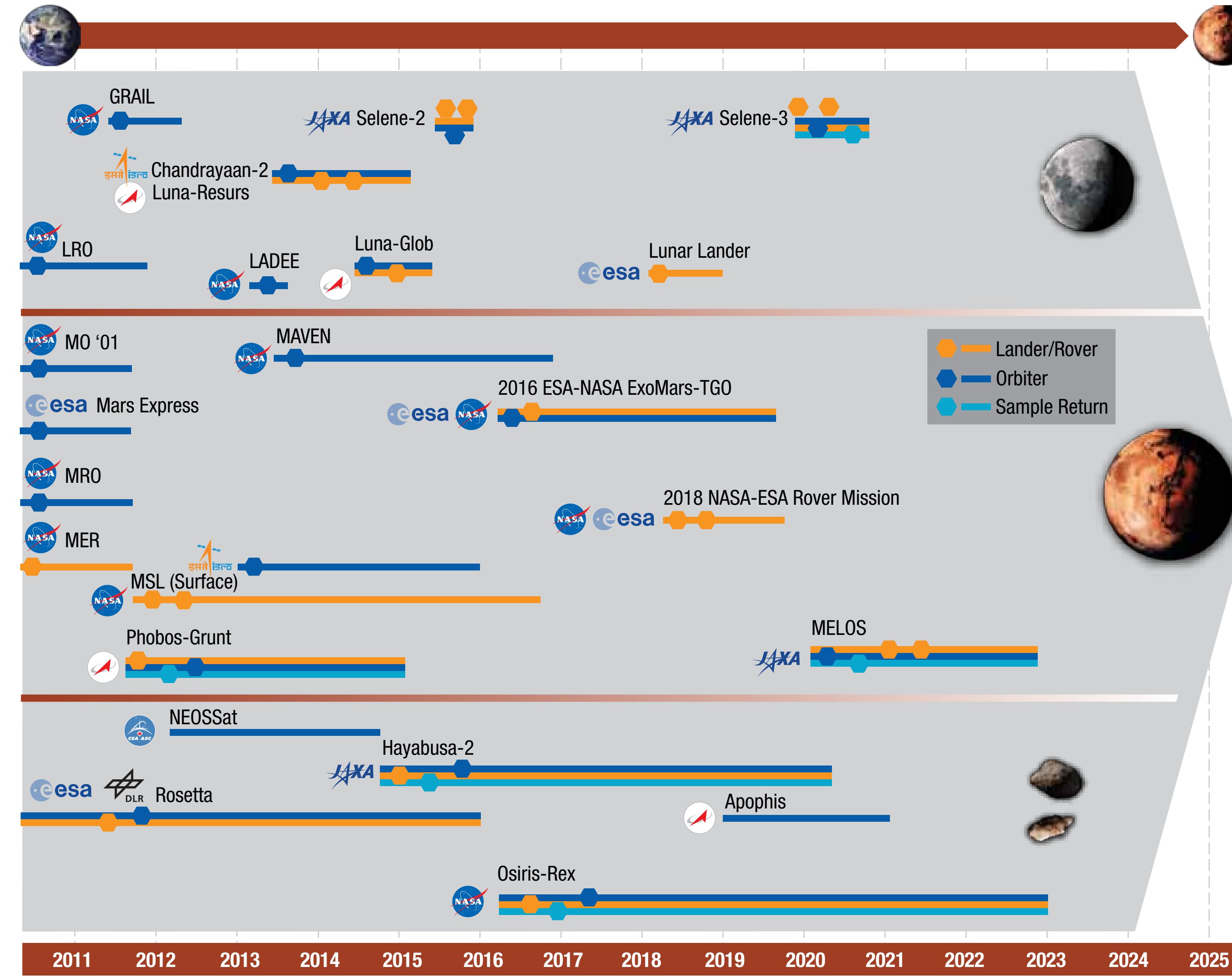
This image taken by JAXA's Selene mission provides lighting information about a potential human landing site.

Whether robotic mission formulation is primarily for scientific investigation or human exploration, there are opportunities to significantly increase the return to each community. The new U.S. Planetary Science Decadal Survey 2011[2] acknowledges this potential, encouraging the human exploration community to take into account significant scientific objectives, while recognizing that certain robotic science missions have great potential for filling knowledge gaps applicable to human missions.

Taking appropriate steps toward further coordination will increase the value of space exploration investment to our global stakeholder community.

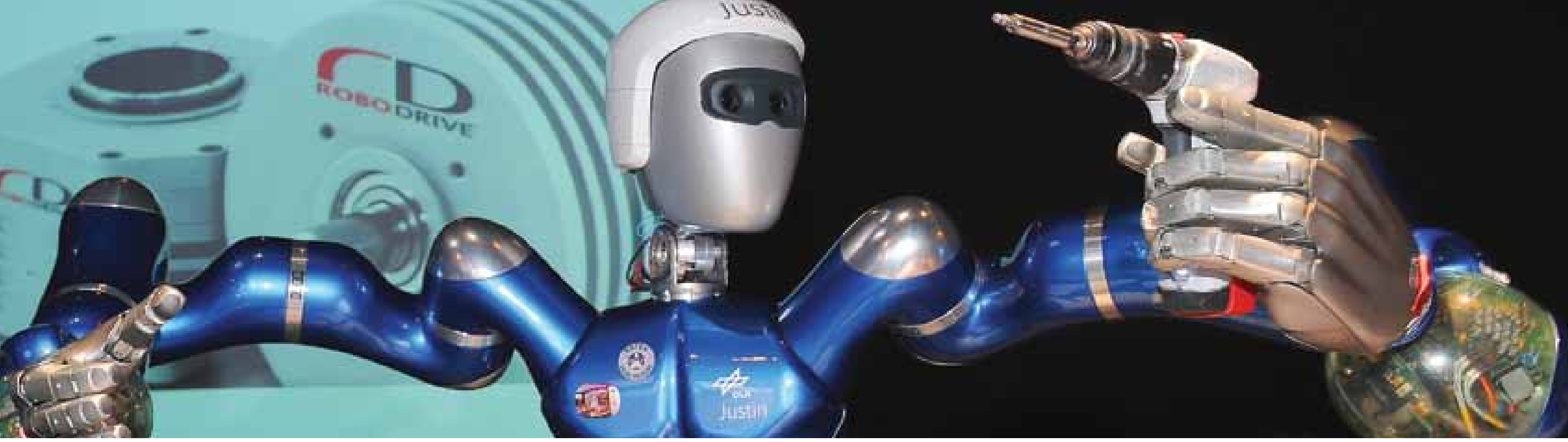
[2] Vision and Voyages for Planetary Science in the Decade 2013–2022, National Research Council, March 7, 2001

Planned Robotic Missions



Observation

➔ Steps should be taken by space agencies to explore the natural synergies between the objectives of robotic planetary science programs and those of the human-robotic exploration strategy. Coordinating future missions of mutual benefit should leverage common interests and create new opportunities for both communities.



DLR's humanoid robot, Justin, demonstrates dexterous tool handling.

Advanced Technologies

Appropriately leveraging global investments in technology development and demonstration is expected to accelerate the availability of critical capabilities needed for human exploration missions. No one agency can invest robustly in all the needed technology areas that represent key challenges for executing human missions beyond low-Earth orbit.

Marigold growth experiment using lunar soil simulant, Ukraine.

Robotics demonstration — DLR's Justin greets the next generation.

Technology development is strategic for all agencies since participation to international missions materializes mainly through technology contributions. Hence, technology development is a competitive area and agencies want to identify where they should focus their investments to maximize their contribution potential. To be successful, an international space exploration program should provide interesting and achievable opportunities for all participating agencies.

Therefore, agencies have begun sharing information on their investment areas. Categorizing the many key systems and technologies needed for space exploration facilitates information sharing among agencies. To start this process, the ISECG has used the technology area categorization defined by NASA's Office of the Chief Technologist[3].

The following table represents the first compilation of initial agency inputs to the ISECG process. It provides a good general overview of the challenges and can serve as an effective starting point for a more detailed mapping of needed technology advancements to ISECG mission scenarios as the technology discussions mature.

[3] Details can be found at http://www.nasa.gov/pdf/501317main_STR-Overview-Final_rev3.pdf

Categorization of Proposed Technology Developments

Technology Area	ASI	CNES	CSA	DLR	ESA	JAXA	KARI	NASA	NSAU	Roscosmos	UKSA
Launch Propulsion Systems (TA01) Enhance existing solid or liquid propulsion technologies by lower development and operations costs, improved performance, availability, and increased capability.					●	●	●	●	●	●	●
In-Space Propulsion Technologies (TA02) Advancements in conventional and exotic propulsion systems, improving thrust performance levels, increased payload mass, increased reliability, and lowering mass, volume, operational costs, and system complexity.	●	●			●	●		●		●	●
Space Power and Energy Storage (TA03) Improvements to lower mass and volume, improve efficiency, enable wide temperature operational range and extreme radiation environment over current state-of-the-art space photovoltaic systems, fuel cells, and other electrical energy generation, distribution, and storage technologies.	●			●	●	●		●		●	●
Robotics, Telerobotics and Autonomous Systems (TA04) Improvements in mobility, sensing and perception, manipulation, human-system interfaces, system autonomy are needed. Advancing and standardizing interfaces for autonomous rendezvous and docking capabilities will also be necessary to facilitate complex in-space assembly tasks.		●	●	●	●	●	●	●		●	●
Communication and Navigation (TA05) Technology advancements to enable higher forward & return link communication data rates, improved navigation precision, minimizing latency, reduced mass, power, volume and life-cycle costs.	●	●	●	●	●	●	●	●	●	●	
Human Health, Life Support and Habitation Systems (TA06) Improvements in reliability, maintainability, reduced mass and volume, advancements in biomedical countermeasures, and self-sufficiency with minimal logistics needs are essential for long-duration spaceflight missions. In addition, advancements in space radiation research is required, including advanced detection and shielding technologies.	●	●	●	●	●	●	●	●		●	●
Human Exploration Destination Systems (TA07) Technology advancements with In Situ Resource Utilization (ISRU) for fuel production, O_2, and other resources, improved mobility systems including surface, off-surface and extravehicular activity (EVA) and extravehicular robotics (EVR), advanced habitat systems, and advancements in sustainability & supportability technologies.			●	●	●	●		●		●	●
Science Instruments, Observatories and Sensor Systems (TA08) Technologies to advance current state-of-the-art for remote sensing instruments/sensors for scientific instruments, advanced scientific observatories, and in situ instruments/sensors of planetary samples.	●	●	●	●	●	●	●	●	●	●	●

Technology Area	ASI	CNES	CSA	DLR	ESA	JAXA	KARI	NASA	NSAU	Roscosmos	UKSA
Entry, Descent, and Landing Systems (TA09) Human-class capabilities for Mars entry, descent, and landing; technologies advancing low-mass high velocity Thermal Protection Systems (TPS), atmospheric drag devices, deep-throttling engines, landing gear, advanced sensing, aero-breaking, aero-capture, etc. Soft precision landing capability is also needed, e.g., for lunar missions.	●	●	●	●	●	●		●		●	●
Nanotechnology (TA10) New advanced materials for reducing vehicle & structural mass, improved functionality and durability of materials, and unique new capabilities such as enhanced power generation & storage, nanopropellants for propulsion, and nanofiltration for improved astronaut heath management.					●			●			
Modeling, Simulation, Information Technology and Processing (TA11) Advancements in technologies associated with flight & ground computing, integrated s/w and h/w modeling systems, simulation, and information processing.		●		●	●	●		●		●	●
Materials, Structures, Mechanical Systems and Manufacturing (TA12) Technology advancements for lightweight structures providing radiation protection, multifunctional structural design and innovative manufacturing. In addition, new technologies associated with reducing design, manufacturing, certification and life-cycle costs.	●		●		●	●		●	●	●	
Ground and Launch Systems Processing (TA13) Technologies to optimize the life-cycle operational costs, increase reliability and mission availability, improve mission safety, reduce mission risk, reducing environmental impacts (i.e., green technologies).								●	●	●	
Thermal Management Systems (TA14) Technology advancement for cryogenic systems performance & efficiency, effective thermal control systems for heat acquisition/transport/rejection, and increase robustness and reduce maintenance for thermal protection systems.	●	●			●	●		●		●	

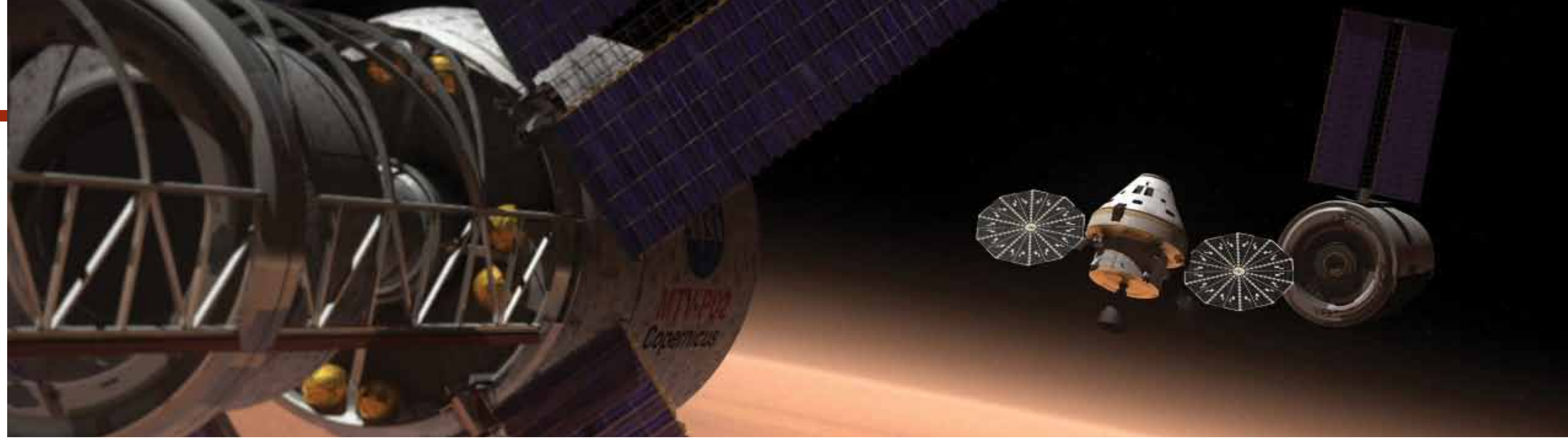
Agencies are working on advancing many technologies needed for exploration. By sharing information on priorities and status, agencies are looking for coordination and future cooperation opportunities that:

- Identify cooperation opportunities for technology demonstration missions.
- Identify gap areas — where the investments are unlikely to provide the needed performance when required — and collaborate to fill these gaps.
- Encourage competition to spur innovation and provide for a more robust overall architecture where different technologies and/or approaches perform critical functions.
- Create partnership opportunities related to usage of unique ground facilities or capabilities.

The goal is to create opportunities for cooperation, while recognizing agency autonomy in investment decisions.

Observation

➔ Agencies participating in ISECG should look for potential cooperation opportunities related to advanced technologies in order to maximize the contribution of individual agency investments toward achievement of their common long-range strategy.



Artist's concept of MPCV orbital operations.

A New Generation of Space Systems and Infrastructure

Human exploration beyond low-Earth orbit will require a new generation of capabilities. These future systems will incorporate technologies still to be discovered and build not only upon existing capabilities and competencies, but also on the lessons learned and experience gained from systems currently in operation. New systems must be particularly reliable and safe because interplanetary resupply missions from Earth cannot reach the crew on short notice and quick return to Earth is not possible. They also will benefit from enhanced interoperability and common interfaces and standards.

Development model of the NASA Multi-purpose Crew Vehicle (MPCV).

By working together on a long-range human exploration roadmap and considering the feasible scenarios contained within, we can reach conclusions regarding the necessity of certain fundamental building blocks. Systems and infrastructure elements that represent the key enabling capabilities of any exploration scenario include the following:

- Heavy-lift launch vehicle
- Crew transportation capability, capable of interplanetary return velocities
- In-space propulsion stage large enough to transport key systems and infrastructure to deep space.
- Servicing and support systems, including extravehicular activity and robotics systems

Activities that are currently underway include heavy-lift launch and crew transportation vehicles along with advanced extravehicular activity suits, where systems are in work by NASA and Roscosmos. Several agencies are investing in, or have significant competencies in, the area of advanced robotics systems. These first steps in implementing the capability-driven framework of the future exploration architecture provide near- and long-term opportunities for coordination and cooperation.

Looking forward, several space agencies are undertaking exploration architecture and system studies. These studies are mainly intended to inform individual decision making regarding exploration mission scenarios and agency roles.

By collaboratively working within ISECG to define mission scenarios and the design reference missions included within, agencies are able to make individual decisions, which may align their studies with emerging international consensus on exploration missions and architectures.

Habitation Demo (Antarctica).

Analogues to Simulate Extreme Environments of Space

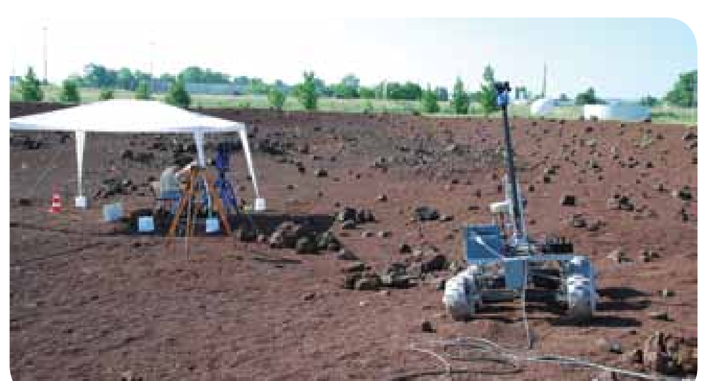
A wide range of terrestrial analogues are in use today to simulate exploration missions, helping prepare for exploration beyond low-Earth orbit. These activities allow access to relevant analogue environments that enable testing of exploration technologies, conceptual systems and their interoperability, as well as concepts for operations and exploration. They also provide an important opportunity for public engagement in a setting that brings together students, astronauts, scientists and engineers, builds networking and strengthens partnerships. Analogue environments are also used to support research into human health and performance questions.

Agencies have begun to share information regarding analogue activities, identifying partnership opportunities that could increase the return on analogue mission investments.

There are individual and joint analogue activities ongoing in several countries. Agencies are interested in sharing their planning and lessons learned with the idea of advancing global preparations for exploration and finding partnerships.

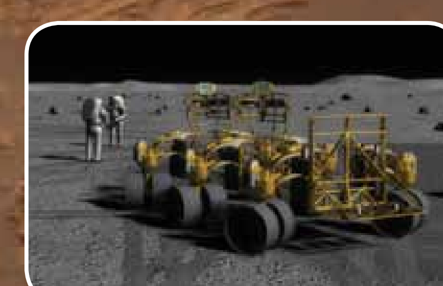
Canadian Juno Tandem Rover carrying the Regolith Environment Science Oxygen & Lunar Volatile Extraction (RESOLVE) payload and the Tridar navigation unit at Mauna Kea deployment site in 2010.

Desert RATS (Arizona, USA).



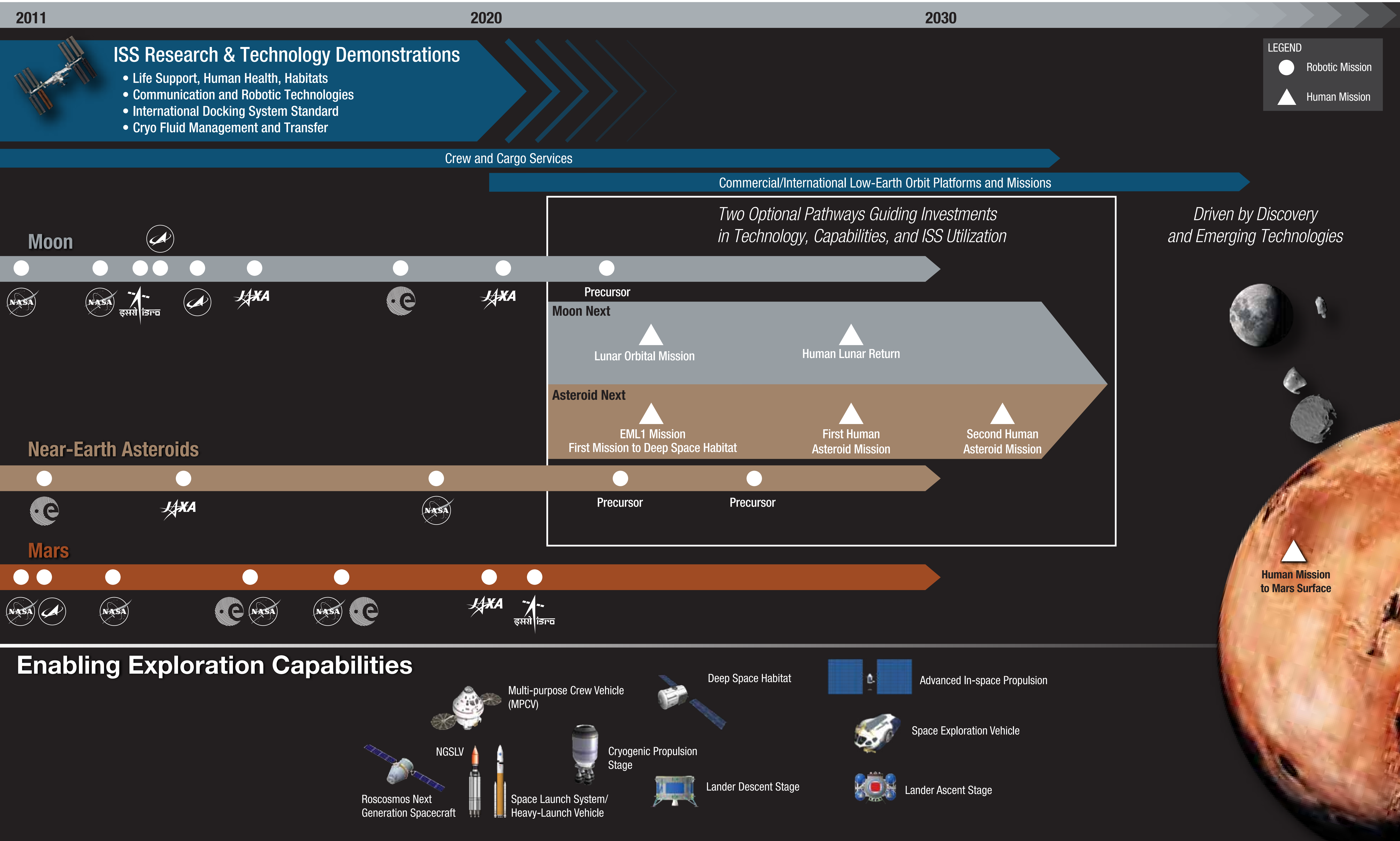
Experimental rover testing in CNES Mars-yard.

Chapter 5. Conclusion



The Global Exploration Roadmap reflects international efforts to define pathways for human exploration of the solar system, with Mars as the ultimate goal within our sights. International cooperation will not only enable these challenging missions, but also increase the probability of their success. Two feasible pathways have been identified and, over time, updates to this roadmap will continue to reflect the efforts of participating agencies to collaboratively develop exploration mission scenarios and coordinate their preparatory activities.

Global Exploration Roadmap



Olympus Mons, Mars.

Conclusion

International coordination and cooperation expands the breadth of human space exploration beyond what any one nation may accomplish on its own and increases the probability of success of human and robotic space exploration initiatives. More importantly, it will enable the complex and challenging missions to the Moon, asteroids, and Mars. Achieving the vision of sustainable human space exploration, including human missions to Mars, requires political support and resources over an extended period of time.

Continuation of the Global Exploration Roadmap and development of coordinated national efforts will require considerable dialog on how to align our policies and plans, as well as address the intergovernmental considerations that affect its successful implementation. Decisions regarding destination sequencing will not be made by the ISECG, but will follow national policy decisions and international consultation at multiple levels — informed by the ISECG's work to collaboratively advance exploration architectures and mission designs. In the coming years, many nations will be developing their domestic policy and legal frameworks to most effectively implement sustainable human space exploration.

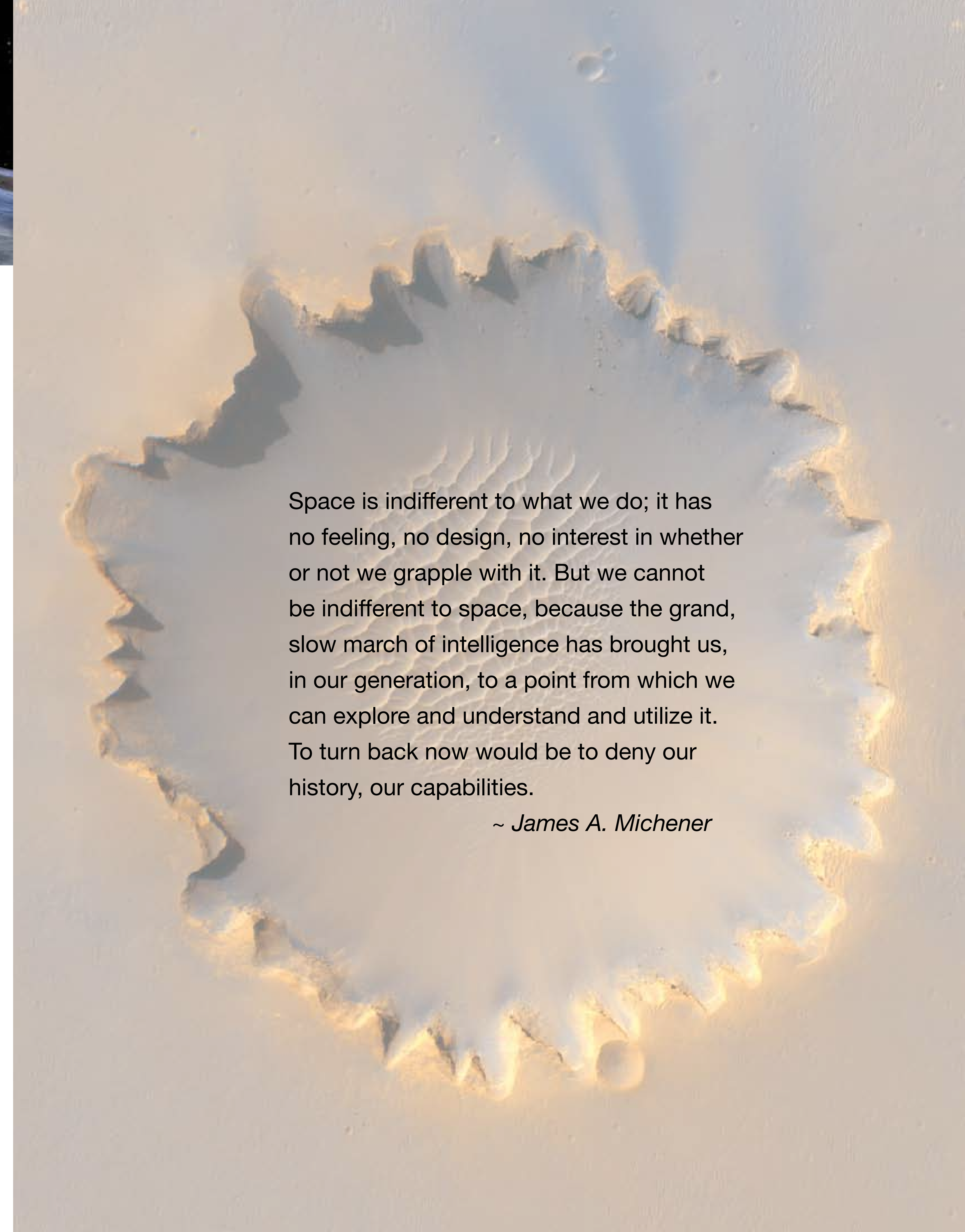
Additionally, as noted in the Global Exploration Strategy Framework Document, for private industry to be confident about investing, it needs the certainty of a long-term commitment to space exploration, the opportunity to introduce its ideas into government thinking, and the rule of law. This means common understandings on such difficult issues as property rights and technology transfer.

While this document does not create commitments of any kind on behalf of any of the participants, the GER is an important step in an evolving process toward achieving a global, strategic, coordinated, and comprehensive approach to space exploration.

The following is a summary of key observations made during the development of the Global Exploration Roadmap, presented in the order they appear in this document. They represent actions that agencies may take to further advance the Global Exploration Strategy:

1. Recognize that interdependency is essential and take steps to its successful implementation.
2. Realize additional opportunities for using the ISS.
3. Increase opportunities for enhancing the human-robotic science partnership.
4. Pursue opportunities for leveraging investments that advance critical exploration technologies.

This and subsequent iterations of the Global Exploration Roadmap should provide the technical basis for informing the necessary binding agreements between agencies and governments. The next iteration of the Global Exploration Roadmap is planned for 2012. Agencies hope to further elaborate the strategies presented in this document and identify additional opportunities for near-term partnerships that contribute to the realization of our journey to destinations beyond low-Earth orbit, including our driving goal of Mars.



Space is indifferent to what we do; it has no feeling, no design, no interest in whether or not we grapple with it. But we cannot be indifferent to space, because the grand, slow march of intelligence has brought us, in our generation, to a point from which we can explore and understand and utilize it. To turn back now would be to deny our history, our capabilities.

~ *James A. Michener*

ISECG

International Space Exploration Coordination Group

The Global Exploration Roadmap is a nonbinding product of the International Space Exploration Coordination Group (ISECG). This first iteration will be followed by periodic updates as the content evolves and matures. ISECG was established by 14 space agencies to advance the Global Exploration Strategy by providing a forum where interested agencies can share their objectives and plans, and explore concepts that make use of synergies. ISECG is committed to the development of products that enable participating agencies to take concrete steps toward partnerships that reflect a globally coordinated exploration effort.

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